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(74) Agent: BERESKIN & PARR; 40th floor, 40 King Street West, Toronto, Ontario M5H 3Y2 (CA).			
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(57) Abstract <p>The invention relates to a method for assaying for the presence of a substance that modulates a cytokine of the TGF-<math>\beta</math> superfamily. A substance which is suspected of modulating a cytokine of the TGF-<math>\beta</math> superfamily and a TGF-<math>\beta</math> binding compound which is not a TGF-<math>\beta</math> receptor and which contains a TRH1 domain, or a portion or mimetic thereof, is reacted with a cytokine of the TGF-<math>\beta</math> superfamily under conditions where the compound, portion or mimetic thereof, and the cytokine are capable of forming a complex. Complexes, free compound and/or cytokine are assayed and compared with a control. The invention also relates to a composition comprising at least one compound which is not a TGF-<math>\beta</math> receptor and which contains the TRH1 domain or a portion, or a mimetic thereof, and a pharmaceutically acceptable carrier, auxiliary or excipient and to methods of treatment using the composition. Further the invention relates to a method of enhancing the activity of growth factors.</p>			

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**Title: MODULATORS OF CYTOKINES OF THE TGF- $\beta$   
SUPERFAMILY AND METHODS FOR ASSAYING FOR SAME**

**FIELD OF THE INVENTION**

5           The present invention relates to methods and compositions for treating conditions requiring modulation of cytokines of the TGF- $\beta$  superfamily, and methods for screening for compounds useful in treating such conditions.

**BACKGROUND OF THE INVENTION**

10           The transforming growth factor beta (TGF- $\beta$ ) superfamily is a group of cytokines that regulate many aspects of cellular function. The structural prototype for the gene superfamily is TGF- $\beta$ . TGF- $\beta$  is produced as a precursor and the precursor structure is shared by most of  
15 the members of the TGF- $\beta$  superfamily. The superfamily includes the TGF- $\beta$  family, the inhibin family, the DPP/VG1 family and the Mullerian Inhibiting Substance Family.

          The TGF- $\beta$  family includes five members, termed TGF- $\beta$ 1 through TGF- $\beta$ 5, all of which form homodimers of  
20 about 25 kd (reviewed in Massague, Annu. Review Cell Biol. 6:597, 1990). The family also includes TGF- $\beta$ 1.2 which is a heterodimer containing a  $\beta$ 1 and a  $\beta$ 2 subunit linked by disulfide bonds. The five TGF- $\beta$  genes are highly conserved over great evolutionary distances. The mature processed  
25 cytokines produced from the members of the gene family show almost 100% amino acid identity between species, and the five peptides as a group show about 60-80% identity.

          All forms of TGF- $\beta$  have been found to reversibly inhibit growth activity in normal, epithelial, endothelial,  
30 fibroblast, neuronal, lymphoid, and hematopoietic cell types (For review see Massague, 1990, Annu. Review Cell Biol. 6:597). In tissue culture, TGF- $\beta$  has been shown to inhibit cell growth by blocking both cdk-4/cyclinD activation and cdk2/cyclinE activity, events required for  
35 G1 to S phase transition (M. E. Ewen, H. K. Sluss, L. L. Whitehouse, D. M. Livingston, Cell 74, 1009 (1993) and A. Koff, M. Ohtsuki, K. Polyak, J. M. Roberts, J. Massague,

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Science 260, 536 (1993)). The antiproliferative action of TGF- $\beta$  has also been demonstrated *in vivo* (Silberstein and Daniel, 1987, Science 237:291-93; and Russell et al, 1988, Proc. Natl. Acad. Sci. USA 85:5126-30).

5 TGF- $\beta$  can also stimulate cell proliferation although the effect may be secondary to other cellular responses. For example, TGF- $\beta$ 1 has been shown to promote the anchorage independent growth of normal rat kidney fibroblasts (Roberts et al., PNAS USA 78:5339, 1981;  
10 Roberts et al, Nature 295:417, 1982 and Twardzik et al., 1985, J. Cell. Biochem. 28:289, 1985) and it induces colony formation of AKR-2B fibroblasts (Tucker et al. Science 226:705, 1984). The inhibitory/stimulatory actions of TGF- $\beta$  may depend on the cell type and the physiological state of  
15 the cells.

TGF- $\beta$  is involved in mediation of cell adhesion. TGF- $\beta$  action on normal mesenchymal, epithelial and lymphoid cells, and some tumor cell lines generally results in the up-regulation of cell adhesion. This up-regulation is  
20 mediated by enhanced synthesis and deposition of extracellular matrix components, decreased pericellular proteolysis, and modification of cell adhesion receptors (Massague, 1990).

Cellular differentiation processes of many cell  
25 lineages can be positively or negatively effected by TGF- $\beta$ . TGF- $\beta$  has been shown to exert positive effects on chondrocyte and osteogenic cell types (Massague, 1990).

The biological actions of TGF- $\beta$  described above suggest a broad role for TGF- $\beta$  in the physiologic setting.  
30 The ability of TGF- $\beta$  to modulate DNA replication, cell differentiation, cell adhesion and extracellular matrix layout indicate a role for TGF- $\beta$  in the generation and modification of signals that guide morphogenic events of embryogenesis. The activity of TGF- $\beta$  as a promoter of  
35 extracellular matrix formation and a regulator of cell migration and development, is a major influence in inflammation and tissue repair processes. In fact, the

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administration of TGF- $\beta$ 1 into wound chambers or to incisional wounds has been shown to accelerate the wound healing response in general (Sporn et al., 1983, Science, 219:1329-31; Roberts et al., 1986, Proc. Natl. Acad. Sci. USA 83:4167-71; and Mustoe et al., 1987, Science 237:1333-36).

The TGF- $\beta$  family of cytokines display an immunosuppressive activity *in vitro* and *in vivo* which is in part attributed to the antiproliferative action of TGF- $\beta$  on lymphocytes (Kehrl et al 1986, J. Immunol. 137:3855), T-lymphocytes (Kehrl et al 1986, J. Exp. Med. 163:1037) and thymocytes (Ristow 1986, PNAS USA 83:5531). An excess of TGF- $\beta$  activity in tissues may lead to an unbalanced deposition of extracellular matrix which may contribute to fibrosis, while a lack of TGF- $\beta$  growth inhibitory activity may lead to oncogenic transformation.

Dis-regulation of TGF- $\beta$  action has been implicated in the pathological processes of many diseases. TGF- $\beta$  has been reported to be a pathogenic mediator in HIV infections and its associated diseases (Lotz, M. and Seth, P. Annals of the NY Acad. of Sciences 685:501, 1993).

TGF- $\beta$  has also been implicated in the development of fibrosis including pulmonary fibrosis (Baecher-Allan and Barth, Regional Immunology 5(3-4):207, 1993), and fibrosis associated with chronic liver disease (Burt, AD, J. of Pathology 170:105, 1993), hepatic veno-occlusive and idiopathic interstitial pneumonitis, which are major causes of morbidity and mortality after bone marrow transplantation (Anscher MS et al. N.Engl.J.Med. 328:1592, 1993), kidney disease (Border et al., Nature 369:360:361, 1992), and radiotherapy or radiation accidents (Martin M. et al Radiation Research 134:63, 1993). TGF- $\beta$ 2 has been found to be elevated in the eye of humans with proliferative vitreoretinopathy and in the skin in systemic sclerosis (Connor et al. J. Clin Invest. 83.:1661, 1989 and Kulozik et al., J. Clin. Invest. 86:917, 1990).

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The use of TGF- $\beta$  and TGF- $\beta$  antagonists to modulate blood pressure is disclosed in PCT/US91/0449 published on December 26, 1991. Recombinant TGF- $\beta$  obtained from Chinese Hamster Ovary cells was reported to induce rapid, significant, and sustained decreases in arterial blood pressure of cynomolgus monkeys receiving daily injections of the recombinant molecule.

The DPP/Vg1 family includes the bone marrow morphogenetic proteins (BMPs), termed BMP1 through BMP7, DPP and Vg1. The BMPs are osteoinductive agents present in adult bone. They are potent initiators of new bone formation and they appear to act on mesenchymal progenitor cells, directing their differentiation into both cartilage and bone-forming cells. It has also been suggested that they play an important role during embryonic skeleton formation (See Review by Rosen and Thies, in Trends in Genetics, 8(3)97, 1992 and references therein). Decapentaplegic (DPP) plays a fundamental role in dorsoventral body patterning and in imaginal disk formation in *Drosophila* (Padgett et al., 1987, Nature, 325:81-84). Vg1 is involved in embryonic development in *Xenopus laevis*.

The inhibin family includes the activins and inhibins. The activins are involved in the regulation of numerous biological processes. For example, they are involved in the proliferation of many tumor cell lines, the control of secretion and expression of the anterior pituitary hormones (EG, FSH, GH, and ACTH), neuron survival, hypothalamic oxytocin secretion, erythropoiesis, placental and gonadal steroidogenesis early embryonic development and the like. Inhibin molecules also help to regulate erythropoiesis and modulate the release of FSH (Mason et al., 1985, Nature 318:659-663 and Ling et al., Nature 321:779, 1986).

The Mullerian Inhibiting Substance family includes Mullerian Inhibiting Substance (MIS) which is an important morphogenetic signal in developing reproductive systems of mammalian embryos (Cate et al, Cell 45:685-698).

The members of the TGF- $\beta$  superfamily may mediate signal transduction through families of related receptors. The cell surface receptors for TGF- $\beta$  and activin are composed of type I and type II receptor chains, both of which contain a cysteine rich extracellular domain and a cytosolic serine/threonine protein kinase domain. The type I and type II receptors form heterodimers which appears to be necessary for cytokine-dependent intracellular signalling (Massague, Cell, 69:1067, 1992 and references therein, and Lin et al., Cell 68:775, 1992).

TGF- $\beta$  binding proteins have been identified which do not function as signalling receptors. The proteoglycan betaglycan is the most widely distributed TGF- $\beta$  binding protein after receptors I and II. Betaglycan is a membrane anchored proteoglycan that binds TGF- $\beta$  via the core protein and it has been suggested that betaglycan acts as a receptor accessory molecule in the TGF- $\beta$  systems (Massague, Cell, 69:1067, 1992 and references therein).

A number of other extracellular matrix proteins have been shown to bind TGF- $\beta$ , including decorin, biglycan, thrombospondin and the serum glycoprotein  $\alpha$ 2-macroglobulin (Y. Yamaguchi, D. M. Mann, E. Ruoslahti, Nature 346, 281 (1990); S. Scholtz-Cherry J.E. Murphy-Ullrich, J. Cell Biol. 122, 923 (1993); O'Conner-McCourt, L.M. Wakefield J. Biol. Chem. 262, 14090 (1987); and J. Massague Curr. Biol. 1, 117 (1991)). Thrombospondin has been shown to bind and activate latent TGF- $\beta$ , but does not neutralize cytokine activity. In contrast, decorin has been shown to neutralize the anti-proliferative activity of TGF- $\beta$  (Yamaguchi et al., Nature 346:281, 1990). Decorin has also been found to antagonize the action of TGF- $\beta$  in vivo using an experimental glomerulonephritis model (Border et al., Nature 360:361, 1992).

Bovine fetuin, is one of the first glycoproteins to be purified from fetal calf serum (FCS). Fetuin is analogous to human  $\alpha$ -2 HS-glycoprotein ( $\alpha$ 2-HS) which is believed to be produced by the liver (Kellerman et al. J.



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- Biol. Chem. 264:14121, 1989). Fetuin has been shown to promote cell growth in vitro without any known cell surface receptor (B. T. Puck, C. A. Waldren, C. Jones, Proc. Natl. Acad. Sci. USA 59, 192 (1968)), and it has been shown to be
- 5 a negative acute phase reactant (J. P. Lebreton, F. Joisel, J. P. Raoult, B. Lannuzel, J. P. Rogez, et al, J. Clin. Invest. 64, 118 (1979). M. Daveau, C. Davrinche, N. Djelassi, J. Lemetayer, N. Julien, et al, FEBS Lett. 273, 79 (1990)). Serum fetuin accumulates in bone (I. R. Dickson,
- 10 A. R. Poole, A. Veis, Nature 256, 430 (1975), J. T. Triffitt, U. Gebauer, B. A. Ashton, M. E. Owen, Nature 262, 226 (1976), G. Rauth, O. Pöschke, E. Fink, M. Eulitz, S. Tippmer, et al, Eur. J. Biochem. 204, 523 (1992)) with highest concentrations found during bone growth. It also
- 15 enhances bone resorption in cultured bone explants in vitro (G. C. Colclasure, W. S. Lloyd, M. Lamkin, W. Gonnerman, R. F. Troxler, et al, J. Clin. Endocrin. Metabolism 66, 187 (1988)), and increases adipogenesis (A. J. Cayatte, L. Kumbia, M. T. R. Subbiah, J. Biol. Chem 265, 5883 (1990)).
- 20 Inflammation is associated with significantly reduced serum fetuin concentrations (J. P. Lebreton, F. Joisel, J. P. Raoult, B. Lannuzel, J. P. Rogez, et al, J. Clin. Invest. 64, 118 (1979). M. Daveau, C. Davrinche, N. Djelassi, J. Lemetayer, N. Julien, et al, FEBS Lett. 273, 79 (1990)).
- 25 Serum fetuin concentrations are also depressed in patients with Paget's disease, an affliction of increased bone turnover which leads to disordered and thickened bone (B. A. Ashton, R. Smith, Clin. Sci. 58, 435 (1980)). In a subset of osteogenesis imperfecta patients, the loss of
- 30 bone is associated with elevated serum fetuin levels.

#### SUMMARY OF THE INVENTION

The present inventors have found that fetuin bound to and antagonized the antiproliferative activity of TGF- $\beta$ , and it was able to inhibit the anti-proliferative

35 activity of TGF- $\beta$  in a dose dependent manner. The present inventors also demonstrated that the action of fetuin as an antagonist of TGF- $\beta$  in tissue culture was due to binding of

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the two proteins. By using surface plasmon resonance which allows the visualisation of macromolecular interactions in real time, it was shown that fetuin could physically bind to TGF- $\beta$ 1. Fetuin was also found to bind to the closely  
5 related cytokine TGF- $\beta$ 2 with similar affinity. Fetuin also bound with highest affinity to bone morphogenic proteins, including immobilized BMP-2, BMP-4 and BMP-6. BMP-2 showed the highest affinity for fetuin and fetuin was found to suppress BMP-2 mediated bone differentiation in vitro.

10 Furthermore, the present inventors have significantly defined a binding domain common to fetuin and TGF- $\beta$  receptor type II designated TGF- $\beta$  Receptor II Homology 1 domain (TRH1), which mediates their binding to cytokines of the TGF- $\beta$  superfamily. The domain is defined  
15 by two disulphide loops which are designated a and b in Figures 6 to 8.

Other proteins such as bovine thyroglobulin were found to contain the TRH1 domain. Thyroglobulin was found to bind to the cytokines BMP-2, BMP-4, TGF- $\beta$ 1 and TGF- $\beta$ 2  
20 with a higher affinity than fetuin. Thyroglobulin was also found to neutralize TGF- $\beta$ 1 activity in a growth inhibition assay.

The present inventors also found that ligand binding and ligand specificity was mediated by the TRH1b  
25 sequence within the TRH1 domain (See Figures 6 and 7 and the Sequence Listing SEQ. ID. NOS. 5 to 7). Synthetic disulphide-looped peptides corresponding to this domain in fetuin and TRH1 bound directly to BMP-2 and TGF- $\beta$ 1 with the same specificity reflecting that of the native proteins.  
30 The TRH1 domain and the TRH1b subdomain have not been found in compounds which have previously been shown to bind to members of the TGF- $\beta$  superfamily and neutralize their activity, for example, decorin.

The finding that fetuin and thyroglobulin complex  
35 with cytokines of the TGF- $\beta$  superfamily through sequences within the TRH1 domain, and that they are antagonists of these cytokines, allows the identification of substances

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which modulate cytokines of the TGF- $\beta$  superfamily, and which accordingly may be used in the treatment of conditions requiring modulation of TGF- $\beta$  superfamily cytokines.

5 Therefore, the present invention relates to a method for assaying for the presence of a substance that modulates a cytokine of the TGF- $\beta$  superfamily which comprises (a) reacting a substance which is suspected of  
10 modulating a cytokine of the TGF- $\beta$  superfamily with a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain, or a portion, or a mimetic thereof, and a cytokine of the TGF- $\beta$  superfamily, under conditions where the TGF- $\beta$  binding compound, portion, or mimetic thereof, and the cytokine are capable of forming a complex,  
15 the TGF- $\beta$  binding compound, portion or mimetic thereof, and/or the cytokine being present in a known concentration, (b) assaying for complexes, free TGF- $\beta$  binding compound, portion or mimetic thereof, and/or cytokine, and (c) comparing with a control.

20 The present invention further relates to the use of a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain, for modulating cytokines of the TGF- $\beta$  superfamily. In particular, the invention relates to the use of these compounds for the treatment of  
25 conditions requiring modulation of cytokines of the TGF- $\beta$  superfamily. The compound may be introduced directly into an individual, or it may be produced indirectly by expression of a gene encoding the TGF- $\beta$  binding compound.

Therefore, the invention relates to a  
30 pharmaceutical composition comprising at least one TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain, or a portion, or a mimetic thereof, and a pharmaceutically acceptable carrier, auxiliary or excipient. The composition may be used as an antagonist of  
35 TGF- $\beta$  superfamily cytokines and therefore will be useful in the treatment of conditions requiring modulation of TGF- $\beta$  superfamily cytokines.

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The invention also relates to a pharmaceutical composition comprising a recombinant molecule containing a gene encoding at least one TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain, or a portion, or a mimetic thereof.

The invention also contemplates a method of treating a subject suffering from a condition requiring modulation of cytokines of the TGF- $\beta$  superfamily comprising administering an effective amount of a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain, or a portion, or a mimetic thereof, or a substance identified by the methods of the invention.

The invention also contemplates a method of enhancing in an individual the activity of a growth factor whose effects are overridden by a cytokine of the TGF- $\beta$  superfamily comprising administering to the individual a composition of the invention, or a substance which is an antagonist of cytokines of the TGF- $\beta$  superfamily identified in accordance with the methods of the invention.

Still further the invention contemplates a method for assaying for a cytokine of the TGF- $\beta$  superfamily in a sample comprising (a) reacting a sample suspected of containing the cytokine with a definite quantity of a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain, or a portion, or a mimetic thereof, and a definite quantity of the cytokine, under conditions where the compound and the cytokine are capable of forming a complex, the compound and/or the cytokine being present in a known concentration, (b) assaying for complexes, free compound and/or cytokine, and (c) comparing with a control.

Other objects, features and advantages of the present invention will become apparent from the following detailed description. It should be understood, however, that the detailed description and the specific examples while indicating preferred embodiments of the invention are given by way of illustration only, since various changes and modifications within the spirit and scope of the

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invention will become apparent to those skilled in the art from this detailed description.

DESCRIPTION OF THE DRAWINGS

The invention will now be described in relation  
5 to the drawings in which:

Figure 1 is a graph showing that bovine fetuin and bovine thyroglobulin neutralize the antiproliferative activity of TGF- $\beta$  on cultures of Mv1Lu cells;

Figure 2 is a sensorgram overlay plot showing  
10 bovine fetuin binding in response units (R.U.) to immobilized TGF- $\beta$ 1;

Figure 3 is a sensorgram overlay plot of the non-binding control human transferrin;

Figure 4 is a sensorgram overlay plot showing  
15 bovine fetuin binding in response units (R.U.) to immobilized BMP-2;

Figure 5 is a sensorgram overlay plot of the non-binding control BSA;

Figure 6 is a multiple alignment of fetuin  
20 sequences from bovine, pig, sheep, rat and human;

Figure 7 is a schematic drawing of the disulfide loop structure of fetuin;

Figure 8 is an alignment of the fetuin and T $\beta$ RII sequences;

Figure 9 is a sensorgram plot showing the binding  
25 of the disulfide-looped TRH1b fetuin peptide to immobilized BMP-2;

Figure 10 is a sensorgram plot showing the lack of binding of reduced and alkylated TRH1b peptide;

Figure 11 shows the sequence of the TGF- $\beta$  type II  
30 receptor;

Figure 12 is a graph showing that bovine fetuin and bovine thyroglobulin neutralize the antiproliferative activity of TGF- $\beta$  cytokines on cultures of Mv1Lu cells;

Figure 13 is a low-ultraviolet CD spectra of 18  
35 amino acid cyclized TRH1 peptides;

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Figure 14 is a bar graph showing competition of TGF- $\beta$ 1 binding to immobilized TRH1 using fetuin and looped TRH1b peptides from TRH1;

Figure 15 is a graph showing that fetuin stimulates proliferation of rat bone-marrow cells treated with dexamethasone for 6 days;

Figure 16 is a graph showing that fetuin inhibits subsequent mineralization in the dexamethasone-treated cultures when present from 1 through 3 weeks; and lacks osteogenic activity alone;

Figure 17 is a graph showing active TGF- $\beta$ , and total TGF- $\beta$  measured in dexamethasone-treated and untreated cultures; and

Figure 18 are graphs showing that neutralizing anti-TGF- $\beta$  antibodies suppressed mineralization and were additive with fetuin in the 1-3 week culture period.

#### DETAILED DESCRIPTION OF THE INVENTION

As hereinbefore mentioned, the present invention relates to a method for assaying for the presence of a substance that modulates cytokines of the TGF- $\beta$  superfamily. A substance which is suspected of modulating cytokines of the TGF- $\beta$  superfamily is reacted with a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain, or a portion, or a mimetic thereof, and a cytokine of the TGF- $\beta$  superfamily. Suitable reaction conditions are employed to permit formation of a complex between the compound and the cytokine. The compound and/or the cytokine are present in a known concentration. The complexes, free compound and/or cytokine are assayed and the results are compared with a control.

"Cytokines of the TGF- $\beta$  superfamily", "Members of the superfamily of TGF- $\beta$  of cytokines", or "TGF- $\beta$  superfamily cytokines" referred to herein includes cytokines having the structural characteristics of the members of the TGF- $\beta$  superfamily. The structural prototype for the gene superfamily is TGF- $\beta$ . TGF- $\beta$  is produced as a precursor which is characterised by having an N-terminal

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hydrophobic signal sequence for translocation across the endoplasmic reticulum, a pro-region, and a C-terminal bioactive domain. Prior to release from the cell, the pro-region is cleaved at a site containing four basic amino acids immediately preceding the bioactive domain (Massague, 1990).

The precursor structure of TGF- $\beta$  is shared by members of the TGF- $\beta$  superfamily cytokines, with the exception of the TGF- $\beta$ 4 precursor which lacks a distinguishable signal sequence. The degree of identity between family members in the C-terminal bioactive domain is from 25 to 90% (See Basler et al. Cell, 73:687, 1993, Figure 2). At least 7 cysteines are conserved in the bioactive domain in all members of the superfamily and all nine cysteines are conserved in the TGF- $\beta$  family and the inhibin  $\beta$  chains. With the exception of Mullerian Inhibiting Substance (MIS) (Cate et al., 1986), the bioactive domain is cleaved to generate a mature monomer.

Examples of cytokines of the TGF- $\beta$  superfamily include the cytokines of the TGF- $\beta$  family, the inhibin family, the DPP/VG1 family and the Mullerian Inhibiting Substance Family.

The TGF- $\beta$  family includes five members, termed TGF1 through TGF- $\beta$ 5, all of which form homodimers of about 25 kd (reviewed in Massague, 1990). The family also includes TGF- $\beta$ 1.2 which is a heterodimer containing a  $\beta$ 1 and a  $\beta$ 2 subunit linked by disulfide bonds. The five TGF- $\beta$  genes are highly conserved over great evolutionary distances. The mature processed cytokines produced from the members of the gene family show almost 100% amino acid identity between species, and the five peptides as a group show about 60-80% identity.

The DPP/VGI family includes the six BMPs termed BMP-2 through BMP-7, Vg1, and DPP. BMPs are 30-40% homologous to members of the TGF- $\beta$  family. BMP2-7 share considerable homology with members of the Inhibin family which includes the inhibins/activins. The inhibins are

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composed of an  $\alpha$  subunit, and either a  $\beta A$  subunit (inhibin A), or a  $\beta B$  subunit (inhibin B). The amino acid identity of the two  $\beta$  subunits is about 60% while the  $\alpha$  subunit sequence is very divergent (about 25% identity). The family  
5 includes inhibin A ( $\alpha.\beta A$  dimer), inhibin B ( $\alpha.\beta B$  dimer), activin A ( $\beta A$  homodimer), and activin AB ( $\beta A.\beta B$  dimer) (See Massague, 1990, and Rose, V. and R.S. Thies, 1992, for reviews on the DPP/VGI family and in particular BMP's).

The Mullerian Inhibiting Substance Family  
10 includes the Mullerian Inhibiting Substance (MIS) homodimer. The deduced sequence of the MIS C-terminal domain is about 25% identical to that of the other members of the superfamily. MIS is a disulfide-linked homodimer of 70-74 kd glycosylated chains that contains the glycosylated  
15 N-terminal extension uncleaved from the C-terminal domain (See review by Massague, 1990, and references referred to therein).

Preferably, the methods and compositions described herein incorporate members of the TGF- $\beta$  family  
20 and the DPP/VGI family, most preferably TGF- $\beta 1$ , TGF- $\beta 2$ , BMP-2, BMP-4 and BMP-6.

Cytokines of the TGF- $\beta$  superfamily can be isolated from natural or recombinant sources. For example, TGF- $\beta 1$  may be synthesized by a variety of normal and  
25 transformed cells in culture (Roberts et al., 1981, Proc. Natl. Acad. Sci. USA 78:5339-5343) and it has been purified from placenta (Frolik et al., 1983, Proc. Natl. Acad. Sci. USA 80:3676-3680), kidney (Roberts et al., 1983, Biochemistry 22:5692-5698), urine (Twardzik et al., 1985,  
30 J. Cell. Biochem. 28:289-297) and blood platelets (Childs et al., 1982, Proc. Natl. Acad. Sci. USA 79:5312-5316). BMP-2, -3, 6 and 7 may be isolated from human and/or bovine bone.

Large quantities of the cytokines may be obtained  
35 by recombinant techniques using host cells transfected with recombinant vectors containing the coding sequence for the cytokine. The cytokines may also be obtained from



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commercial sources. (For example, TGF- $\beta$ 1 may be obtained from Collaborative Research, Bedford, Ma.).

The TGF- $\beta$  binding compound used in the methods and compositions described herein may be a glycoprotein or polypeptide. The compound binds to a cytokine of the TGF- $\beta$  superfamily, preferably TGF- $\beta$ 1, with a  $K_D$  of greater than  $10^{-5}$ , and/or neutralizes the activity of a TGF- $\beta$  cytokine such as TGF- $\beta$ 1 or BMP-2 in a growth inhibition assay as described herein. The TGF- $\beta$  binding compound is not a natural target TGF- $\beta$  receptor namely a type I or type II receptor of TGF- $\beta$  or activin which contain a cytosolic serine/threonine protein kinase domain. The sequence of the TGF- $\beta$  type II receptor is set out in Figure 11 and in the Sequence Listing as SEQ. ID. NO. 1.

The protein portion of the TGF- $\beta$  binding compound contains at least one amino acid sequence of the TRH1 domain, or a portion or a mimetic thereof. The TRH1 domain comprises a region about 43 amino acids in length, containing two disulfide loops designated a and b in Figures 7 and 8. A TRH1 domain may be identified using the GCG routine "findPatterns" and the following pattern: CX{8,14}(N,Q)X{12,16}CX{4,5}(K,R)X{2,6}(S,T)X{4,9}CX{0,2}DX{5,6}(D,E) (See Example 3 herein). The TRH1 domain from fetuin is shown in the Sequence Listing as SEQ. ID. NO. 2 and in Figure 8; the TRH1 domain from the TGF- $\beta$  type II receptor is shown in the Sequence Listing as SEQ. ID. NO. 3 and in Figure 8; and, the TRH1 domain from thyroglobulin is shown in the Sequence Listing as SEQ. ID. NO. 4 and in Figure 8. Preferably, the compound contains a portion of the TRH1 domain having the amino acid sequence of the TRH1b subdomain which contains about 18-20 amino acids. A TRH1b subdomain may be identified using the GCG routine "findpatterns" and the following pattern: CX{4,5}(K,R)X{2,6}(S,T)X{4,9}CX{0,2}DX{5,6}(D,E), or CX{0,1}(V,I,F,Y)X{1,3}(V,W,L)X{0,1}(K,R)X{4,5}(V,I,F)X{1,2}(L,I)X{2,4}CX{0,2}D. The TRH1b subdomain from fetuin, the TGF- $\beta$  type II receptor, and thyroglobulin are

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shown in the Sequence Listing as SEQ. ID. NOS. 5, 6, and 7, respectively, and in Figure 7. It will be appreciated that the terminal amino acids shown in SEQ. ID. NOS. 5, 6, and 7 may be removed to provide an 18-19 TRH1b peptide.

5        Examples of TGF- $\beta$  binding compounds which may be used in the methods and compositions of the invention are fetuin, including human fetuin also known as  $\alpha_2$ -HS glycoprotein, thyroglobulin, kininogens (Kellerman et al. Biochem. J. 247:15, 1987), and TRH1b peptides.

10        The protein portion of the TGF- $\beta$  binding compound may include sequences which are homologous to the amino acid sequence of the TRH1 domain, or a portion thereof such as the TRH1b subdomain. A sequence which is homologous to the TRH1 domain or a portion thereof such as the TRH1b  
15 subdomain is defined as a sequence which has at least about 40% and 70% identity, respectively. A TGF- $\beta$  binding compound containing a homologous sequence should be capable of binding to a TGF- $\beta$  cytokine, preferably TGF- $\beta$ 1, with a  $K_D$  of greater than  $10^{-5}$  and/or neutralizing activity of a  
20 TGF- $\beta$  cytokine such as TGF- $\beta$ 1 or BMP-2 in a growth inhibition assay as described herein.

It will be appreciated that a TGF- $\beta$  binding compound may be modified by substituting amino acids for like amino acids. For example, a basic amino acid may be  
25 substituted with a different basic amino acid, or a hydrophobic amino acid may be substituted with a different hydrophobic amino acid in the TRH1 domain or TRH1b subdomain.

Mimetics of the TGF- $\beta$  binding compounds may also  
30 be used in the methods and compositions of the invention. The term "mimetic" refers to compounds which have a related three dimensional structure i.e. compounds which have one or both of the characteristic disulfide loop structures as shown schematically in Figure 7, preferably the loop  
35 structure designated "b". The selection of mimetics may be done using methods such as described in for example P.S. Farmer, in Drug Design, EJ Ariens, Ed. (Academic Press, New

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York, 1980) Vol. 10, p.119-143; Ball JB, PF Alewood, J. Mol. Recognition 3,55, 1990; BA Morgan and JA Gainer, Annu. Rep. Med. Chem. 24, 243, 1989; and RM Friedinger, Trends Pharmacol. Sci. 10, 270 1989.

5           A TGF- $\beta$  binding compound may also be a chimeric molecule. For example, the TRH1b region of fetuin (SEQ. ID. NO. 5 and Cys 26 to Cys 44 in SEQ. ID. NO.2 ) can be replaced by the corresponding loop from the TGF- $\beta$  type II receptor (SEQ. ID. NO. 6 and Cys 24 to Cys 41 in SEQ. ID. NO. 3).

10           TGF- $\beta$  binding compounds such as fetuin and thyroglobulin may be obtained using conventional isolation and purification techniques. For example, the compounds may be obtained by ammonium sulfate fractionation of fetal calf serum followed by gel filtration chromatography. They may also be obtained from commercial sources (e.g. Sigma, St. Louis, Mo., USA). TGF- $\beta$  binding compounds may also be synthetically constructed using conventional methods such as chemical synthesis using techniques well known in the chemistry of proteins such as solid phase synthesis (Merrifield, 1964, J. Am. Chem. Assoc. 85:2149-2154) or synthesis in homogenous solution (Houbenweyl, 1987, Methods of Organic Chemistry, ed. E. Wansch, Vol. 15 I and II, Thieme, Stuttgart).

25           A TGF- $\beta$  binding compound, and portions thereof, including the TRH1 domain and TRH1b subdomain, may also be expressed in a host cell including bacteria, yeast, insect or mammalian cells, or animals using methods well known in the art (see, for e.g., Itakura et al., U.S. Patent No. 30 4,704,362; Hinnen et al., PNAS USA 75:1929-1933, 1978; Murray et al., U.S. Patent No. 4,801,542; Upshall et al., U.S. Patent No. 4,935,349; Hagen et al., U.S. Patent No. 4,784,950; Axel et al., U.S. Patent No. 4,399,216; Goeddel et al., U.S. Patent No. 4,766,075; and Sambrook et al. 35 Molecular Cloning A Laboratory Manual, 2nd edition, Cold Spring Harbor Laboratory Press, 1989).

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Preferably, the expression system is a mammalian expression system. For example, Chinese Hamster Ovary (CHO) cells may be used to produce a correctly folded and glycosylated fetuin or chimeric fetuin, and to permit  
5 recovery of the protein from serum-free cell culture supernatants. Both a transient and stable approach may be used. The former approach may be based on the SFU virus replicon which can be used to quickly produce relatively large amounts of recombinant protein. The stable approach  
10 may employ the well characterized cytomegalovirus (CMV) promoter which allows for a more permanent and constant source of the protein. The coding region of a cDNA encoding the protein can be cloned out of a cDNA library using the polymerase chain reaction (PCR) amplification techniques  
15 (Mullis et al., U.S. Pat. No. 4,863,195 and Mullis, U.S. Patent No. 4,683,202). The nucleotide sequence may be confirmed by DNA sequencing. A PCR based cloning strategy will allow introduction of convenient restriction sites for subcloning into the expression vectors.

20 A TGF- $\beta$  binding compound, and portions thereof including the TRH1 domain and TRH1b subdomain may be expressed in non-human transgenic animals such as, rats, mice, rabbits, sheep and pigs (see Hammer et al. (Nature 315:680-683, 1985), Palmiter et al. (Science 222:809-814,  
25 1983), Brinster et al. (Proc Natl. Acad. Sci USA 82:44384442, 1985), Palmiter and Brinster (Cell. 41:343-345, 1985) and U.S. Patent No. 4,736,866).

It will be appreciated that the selection of the TGF- $\beta$  binding compound and the TGF- $\beta$  superfamily cytokine  
30 in the method of the invention will depend on the nature of the substance to be assayed. It will also be appreciated that the selection of the compound and TGF- $\beta$  superfamily cytokine in the method of the invention will allow for the identification of a specific substance that affects a  
35 specific interaction. Thus, the identification of the specific site of binding of the TRH1 domain to TGF- $\beta$  superfamily cytokines by the present inventors allows the

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identification of specific substances that modulate TGF- $\beta$  superfamily cytokines.

Conditions which permit the formation of cytokine-TGF- $\beta$  binding compound complexes may be selected  
5 having regard to factors such as the nature and amounts of the cytokine and the TGF- $\beta$  binding protein.

The complexes, and free compounds and cytokines in the methods of the invention may be isolated by conventional isolation techniques, for example, salting  
10 out, chromatography, electrophoresis, gel filtration, fractionation, absorption, polyacrylamide gel electrophoresis, agglutination, or combinations thereof.

The complexes or free compounds or cytokines may be assayed using known methods. To facilitate the assay of  
15 the components, antibody against the compound or cytokine which may be labelled, or a labelled compound or cytokine may be utilized. The components may also be assayed by determining the ability to neutralize activity of a TGF- $\beta$  cytokine such as TGF- $\beta$ 1 or BMP-2 in a growth inhibition  
20 assay as described herein.

As controls, the methods of the invention may be carried out in the absence of the substance which is suspected of modulating cytokines of the TGF- $\beta$  superfamily, or in the presence of a substance which is known to  
25 modulate cytokines of the TGF- $\beta$  superfamily.

The TGF- $\beta$  binding compounds and TGF- $\beta$  superfamily cytokines may be used to prepare antibodies and the antibodies may be used to facilitate isolation and separation of complexes and free compound, or cytokine. As  
30 described below, antibodies to the TRH1 domain and portions thereof may also be used to neutralize the activity of a TGF- $\beta$  cytokine by blocking its binding to its native receptor, and accordingly they may allow therapeutic intervention in cases where there is excessive TGF- $\beta$   
35 cytokine activity such as cases of fibrosis, or where TGF- $\beta$  serves as an autocrine growth factor for tumors. They may also be used for assaying for the presence of a TGF- $\beta$

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superfamily cytokine in a biological sample in specific diagnostic applications.

Within the context of the present invention, antibodies are understood to include monoclonal antibodies, polyclonal antibodies, antibody fragments (e.g., Fab, and F(ab')<sub>2</sub> and recombinantly produced binding partners.

Polyclonal antibodies may be readily generated by one of ordinary skill in the art from a variety of warm-blooded animals such as horses, cows, various fowl, rabbits, mice, or rats. The present inventors have immunized rabbits with a TRH1b peptide and obtained an animal which displays clinical symptoms similar to those found with autoimmune conditions. In particular, the rabbits showed fibrosis of their foot pads, and there was evidence of inflammatory responses in the liver.

Monoclonal antibodies may also be readily generated using conventional techniques (see U.S. Patent Nos. RE 32,011, 4,902,614, 4,543,439, and 4,411,993 which are incorporated herein by reference; see also Monoclonal Antibodies, Hybridomas: A New Dimension in Biological Analyses, Plenum Press, Kennett, McKearn, and Bechtol (eds.), 1980, and Antibodies: A Laboratory Manual, Harlow and Lane (eds.), Cold Spring Harbor Laboratory Press, 1988, which are also incorporated herein by reference). Binding partners may also be constructed utilizing recombinant DNA techniques to incorporate the variable regions of a gene which encodes a specifically binding antibody (See Bird et al., Science 242:423-426, 1988).

Antibodies specific for some of the cytokines may also be obtained from commercial sources. For example, antibodies to cytokines of the TGF- $\beta$  family may be obtained from American Diagnostics Inc., CT. USA, Oncogene Science, NY, USA, and Dimension Laboratories, Mississauga, Canada.

The antibodies against the compound or cytokines may be labelled using conventional methods with various enzymes, fluorescent materials, luminescent materials and radioactive materials. Examples of suitable enzymes include

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horseradish peroxidase, biotin, alkaline phosphatase,  $\beta$ -galactosidase, or acetylcholinesterase; examples of suitable fluorescent materials include umbelliferone, fluorescein, fluorescein isothiocyanate, rhodamine, dichlorotriazinylamine fluorescein, dansyl chloride or phycoerythrin; an example of a luminescent material includes luminol; and examples of suitable radioactive material include radioactive phosphorous  $^{32}\text{P}$ , iodine  $^{125}\text{I}$ ,  $^{131}\text{I}$  or tritium. Antibodies specific for the compound or cytokine may also be coupled to electron dense substances, such as ferritin or colloidal gold, which are readily visualised by electron microscopy.

The TGF- $\beta$  binding compound or cytokine used in the method of the invention may be insolubilized. For example, they may be bound to a suitable carrier. Examples of suitable carriers are agarose, cellulose, dextran, Sephadex, Sepharose, carboxymethyl cellulose polystyrene, filter paper, ion-exchange resin, plastic film, plastic tube, glass beads, polyamine-methyl vinyl-ether-maleic acid copolymer, amino acid copolymer, ethylene-maleic acid copolymer, nylon, silk, etc. The carrier may be in the shape of, for example, a tube, test plate, beads, disc, sphere etc.

The insolubilized compound or cytokine may be prepared by reacting the material with a suitable insoluble carrier using known chemical or physical methods, for example, cyanogen bromide coupling.

The methods of the invention may be used to assay for a substance that modulates TGF- $\beta$  superfamily cytokines preferably a suspected agonist or antagonist. Generally, an antagonist may constitute any molecule with similar binding activity to a TGF- $\beta$  superfamily cytokine but incapable of propagating the biological response normally induced by the cytokine. An antagonist may also be a molecule that mimics the binding site on the receptor for the cytokine. For example, an antagonist constitutes a molecule containing the TRH1 domain, and in particular the TRH1b subdomain. As

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described in detail herein compounds such as fetuin and thyroglobulin which contain the TRH1 domain (and the TRH1b subdomain) are antagonists of cytokines of the TGF- $\beta$  superfamily. On the other hand, an agonist constitutes a molecule which binds to the specific binding site on the receptor for the cytokine i.e. the TRH1 domain or the TRH1b subdomain, in some advantageous manner compared to the natural cytokine. The agonist or antagonist may be an endogenous physiological substance or it may be a natural or synthetic drug.

The invention also relates to a pharmaceutical composition comprising at least one TGF- $\beta$  binding compound. The invention also contemplates pharmaceutical compositions containing substances identified using the methods described herein. The pharmaceutical compositions may be used as an agonist or antagonist of the interaction of a TGF- $\beta$  cytokine and a T $\beta$ RII. The composition preferably contains fetuin, more preferably human fetuin, also known as  $\alpha$ -2 HS-glycoprotein, or a chimeric fetuin as described herein. Fetuin is particularly suitable as a pharmacological agent since it is a natural human compound which is non-immunogenic, and it can be produced as a recombinant molecule as described herein.

The pharmaceutical compositions of the invention contain at least one TGF- $\beta$  binding compound, or substance identified using the methods of the invention, alone or together with other active substances. Such pharmaceutical compositions can be for oral, topical, rectal, parenteral, local, inhalant or intracerebral use. They are therefore in solid or semisolid form, for example pills, tablets, creams, gelatin capsules, capsules, suppositories, soft gelatin capsules, gels, membranes, tubelets. The compositions of the invention may also be conjugated to transport molecules such as transferrin to facilitate transport of the composition across the blood brain barrier.



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The pharmaceutical composition of the invention may also contain additional therapeutic compounds. For example, glucocorticoids which are widely used in the treatment of many conditions including rheumatoid  
5 arthritis, chronic active hepatitis, and asthma may be included in the pharmaceutical compositions of the invention.

The pharmaceutical compositions of the invention can be intended for administration to humans or animals.  
10 Dosages to be administered depend on individual needs, on the desired effect and on the chosen route of administration.

The pharmaceutical compositions can be prepared by per se known methods for the preparation of  
15 pharmaceutically acceptable compositions which can be administered to patients, and such that an effective quantity of the active substance(s) is combined in a mixture with a pharmaceutically acceptable vehicle. Suitable vehicles are described, for example, in  
20 Remington's Pharmaceutical Sciences (Remington's Pharmaceutical Sciences, Mack Publishing Company, Easton, Pa., USA 1985).

On this basis, the pharmaceutical compositions include, albeit not exclusively, the active compound or  
25 substance in association with one or more pharmaceutically acceptable vehicles or diluents, and contained in buffered solutions with a suitable pH and iso-osmotic with the physiological fluids.

The invention also relates to a composition  
30 comprising a recombinant molecule containing a gene encoding at least one TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains the TRH1 domain, or a portion, or a mimetic thereof. The recombinant molecule also contains suitable transcriptional or translational  
35 regulatory elements. Suitable regulatory elements may be derived from a variety of sources, and they may be readily selected by one of ordinary skill in the art. Examples of

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regulatory elements include: a transcriptional promoter and enhancer or RNA polymerase binding sequence, a ribosomal binding sequence, including a translation initiation signal. Additionally, depending on the vector employed, other genetic elements, such as selectable markers, may be incorporated into the recombinant molecule. The recombinant molecule may be introduced into cells of a subject using in vitro delivery vehicles such as retroviral vectors, adenoviral vectors and DNA virus vectors. They may also be introduced into such cells in vivo using physical techniques such as microinjection and electroporation or chemical methods such as coprecipitation and incorporation of DNA into liposomes. The compositions may also be delivered in the form of an aerosol or by lavage.

The present invention also provides for methods in which a patient suffering from a condition requiring modulation of cytokines of the TGF- $\beta$  superfamily is treated with an effective amount of a TGF- $\beta$  binding compound. Therapeutic methods comprising administering agonists or antagonists identified with the methods of the present invention are also within the scope of the present invention.

The TGF- $\beta$  binding compounds, substances identified using the method of the invention, antibodies, and compositions containing same, may be used in a variety of applications. Since the TGF- $\beta$  cytokines are involved in many biological processes, the compounds, substances, antibodies and compositions can be applied to the modulation of these processes.

Agonists of cytokines of the TGF- $\beta$  family identified using the method of the invention may be used for example, to stimulate wound healing, to suppress the growth of TGF- $\beta$  sensitive tumors, to suppress the immune response, and to stimulate angiogenesis. The immune response may be suppressed in transplant cases to reduce the rejection of the transplanted organ.

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Antagonists of cytokines of the TGF- $\beta$  family can be used to block the binding of an endogenous TGF- $\beta$  to its natural target receptors thereby blocking cell proliferative or inhibitory signals generated by the ligand-receptor binding event. Antagonists such as TGF- $\beta$  binding compounds and antibodies would thereby stimulate immune responses and reduce the deposition of extracellular matrix. Accordingly, antagonists would be particularly suitable for the treatment of conditions such as fibrosis including pulmonary fibrosis, fibrosis associated with chronic liver disease, hepatic veno-occlusive and idiopathic interstitial pneumonitis, kidney disease, and radiotherapy or radiation accidents; proliferative vitreoretinopathy; systemic sclerosis; autoimmune disorders such as rheumatoid arthritis, Graves disease, systemic lupus erythematosus, Wegener's granulomatosis, sarcoidosis, polyarthritis, pemphigus, pemphigoid, erythema multiforme, Sjogren's syndrome, inflammatory bowel disease, multiple sclerosis, myasthenia gravis keratitis, scleritis, Type I diabetes, insulin-dependent diabetes mellitus, Lupus Nephritis, and allergic encephalomyelitis; proliferative disorders including various forms of cancer such as leukemias, lymphomas (Hodgkins and non-Hodgkins), sarcomas, melanomas, adenomas, carcinomas of solid tissue, hypoxic tumors, squamous cell carcinomas of the mouth, throat, larynx, and lung, genitourinary cancers such as cervical and bladder cancer, hematopoietic cancers, head and neck cancers, and nervous system cancers, benign lesions such as papillomas, arthrosclerosis, angiogenesis, and viral infections, in particular HIV infections.

Antagonists of cytokines of the TGF- $\beta$  family may also be used to elevate blood pressure through the inhibition of hypotension induced by TGF- $\beta$ . Methods which lower and/or maintain the level of circulating TGF- $\beta$  in a subject may result in a similar pressor effect and may prevent excessive hypotensive signal generation and resulting hypotension.

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The stimulation of FSH release by activin can be enhanced by the administration of a specific TGF- $\beta$  binding compound. The compound would prevent the formation of a complex between activin and its natural receptor which would then act to stimulate the release of FSH. Therefore, the TGF- $\beta$  binding compound would reduce the effect of activin by blocking the normal interaction between activin and activin receptor. Accordingly, the TGF- $\beta$  binding compound can be applied to the control of fertility in humans, domesticated animals, and animals of commercial interest. The action of activin on erythropoiesis can also be modulated by administering a modulating effective amount of a TGF- $\beta$  binding compound. The compounds, substances, antibodies and compositions of the invention can also be used in the diagnosis and/or treatment of activin-dependent tumors or for enhancing the survival of brain neurons.

The present inventors' work supports a role for fetuin and TGF- $\beta$  superfamily cytokine interactions in bone cell differentiation. The present inventors have found that fetuin has a greater affinity for BMPs, and fetuin and BMPs are known to be co-localized in developing bone. The present inventors have also shown that fetuin suppresses BMP-2 dependent bone differentiation in vitro. Therefore, substances that modulate TGF- $\beta$  superfamily cytokines, in particular BMP-2 to BMP-7, identified herein and using the methods of the invention may be used to induce bone formation, and for example, they can be used to repair or heal fractures, treat osteoporosis, address dental problems, and they may be used with implants to encourage bone growth.

TGF- $\beta$  has been found to control proliferation and differentiation of several cell types specific to bone including mesenchymal precursor cells, chondrocytes, osteoblasts and osteoclasts. TGF- $\beta$  has been shown to block the differentiation of normal rat diploid fetal osteoblasts in vitro (E.C. Breen et al. J. Cell. Physiol. 160:323-335, 1994). The effect is restricted to the proliferative phase

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of the culture before the cells express the mature osteoblastic phenotype. The present inventors have shown that fetuin stimulated cell growth during the proliferative phase, and it inhibited deposition of calcium-containing matrix i.e. bone tissue, following the proliferative phase. Therefore, bone formation (in particular for the applications discussed above) may be stimulated by modulating the early effects of TGF- $\beta$  cytokines by administering a TGF- $\beta$  binding compound, and/or by modulating the late effects of the TGF- $\beta$  cytokines by administering an agonist of a TGF- $\beta$  cytokine identified using the methods described herein. Disorders where there is too much bone formation (for example, achondroplasia, Paget's disease, and osteopetrosis) may also be treated by modulating TGF- $\beta$  cytokines using TGF- $\beta$  binding compounds, and substances identified using the methods of the invention.

TGF- $\beta$  binding compounds and substances identified using the methods of the invention, may also be used in conjunction with glucocorticoids which are used in the treatment of many diseases including rheumatoid arthritis, chronic active hepatitis, asthma, and in posttransplant tissue rejection. Chronic glucocorticoid therapy has been associated with induced osteoporosis which is a major risk factor for bone loss. TGF- $\beta$  has been found to play a role in glucocorticoid regulation of bone cell functions (Oursler, M.J. et al, Endocrinology, 133(5), p.2187, 1993).

The utility of the compounds, antibodies, and compositions of the invention may be confirmed in animal experimental model systems. For example, therapeutic utility in fibrotic conditions may be tested by examining the susceptibility of mice to the induction of pulmonary fibrosis by bleomucin sulfate (Baecher-Allan, Regional Immunology 5(3-4):207, 1993). The well-characterized pig model of radiation induced fibrosis described in Martin et al. (Radiation Research 134(1)63, 1993), and the experimental glomerulonephritis model described in Border

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et al. (Nature 360:361, 1992) may also be utilised. Other models which may be useful in confirming the utility of the compounds, substances and compositions of the present invention include those for wound healing (e.g. the fetal tissue repair model described in Bleacher et al. Dermatologic Clinics 11(4):677, 1993), bone repair (e.g. bone induction in rats - Yasko, AW, et al., Orthop. Trans. 15:501, 1991; sheep femur - Gerhart TN et al, Trans. 37 Annual Meeting Orthop. Res. Soc. Anaheim CA Catherson, B, ed) 16(1), p.172, 1991; and dog mandible- Toriumi DM et al, Archiv. Otolaryngol. Head Neck Surg. 117:1101-1112, 1991), and autoimmune diseases (e.g. MRL-lpr/lpr mice are a model for systemic lupus erythematosus, and NZBxNZWf1 mice which demonstrate clinical symptoms comparable to those found with human autoimmune diseases -Theofilopoulos and Dixon, Adv. Immunol. 37, 1985).

It would also be apparent to one skilled in the art that the above described methods, compounds, substances, antibodies, and compositions may be used to study the cytokines of the TGF- $\beta$  superfamily and, accordingly, will provide further insight into the role of the cytokines in growth, differentiation and morphogenesis.

Cytokines of the TGF- $\beta$  family arrest the growth of cells thereby overriding the action of other growth factors such as EGF, bFGF, IL-1 $\alpha$ , IL-1 $\beta$ , Int-2, keratinocyte growth factor, IL-2, GM-CSF, G-CSF, CNTF, EGF, TGF $\alpha$ , human growth hormone, NGF, PDGF, insulin, IGF-1, IGF-2, bombyxin, glial growth factor TNF, and CD40 ligand (Ewen et al., Cell 74:1009, 1993). For effective use of growth factors in a clinical setting, it would be desirable to reduce the activity of TGF- $\beta$  cytokines concomitantly.

Accordingly, the invention also contemplates a composition comprising a TGF- $\beta$  binding compound in combination with a growth factor whose effects are overridden by a cytokine of the TGF- $\beta$  superfamily. The invention also relates to a method of enhancing treatment of an individual with a growth factor whose effects are

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overridden by a cytokine of the TGF- $\beta$  superfamily comprising concomitantly administering with the growth factor a TGF- $\beta$  binding compound which is not a receptor of TGF- $\beta$  cytokine and which contains a TRH1 domain. Other  
5 antagonists of the binding of cytokines of the TGF- $\beta$  superfamily identified using the methods of the invention may also be used in these compositions and methods to enhance the activity of growth factors.

Another application of the present invention is  
10 the assay of samples for the presence or absence of members of the TGF- $\beta$  superfamily of cytokines. For example, serum from a patient displaying symptoms related to pathways mediated by members of the superfamily of TGF- $\beta$  cytokines can be assayed to determine if the observed symptoms are  
15 perhaps caused by over-or under-production of such a cytokine. The assays can be carried out in a variety of ways as can readily be identified by one of skill in the art. For example, competitive assays can be employed as well as immunological assays using antibodies of the  
20 invention such as radioimmunoassays, ELISA, ERMA, and the like.

In an embodiment of the invention a competitive binding assay is provided for assaying for a cytokine of the TGF- $\beta$  superfamily in a sample comprising (a) reacting  
25 a sample suspected of containing the cytokine with a definite quantity of a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain or a portion, or a mimetic thereof, and a definite quantity of the cytokine, under conditions where the compound and the  
30 cytokine are capable of forming a complex, the compound and/or the cytokine being present in a known concentration, (b) assaying for complexes, free compound and/or cytokine, and (c) comparing with a control.

The method may be used to assay for TGF- $\beta$   
35 cytokines in tissues and biological samples for example clinical samples of blood, blood product, serum, body fluids, secretions, faeces, washings such as throat

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washings, tissue homogenates and cell culture fluids containing or suspected of containing the cytokines. The cytokines and TGF- $\beta$  binding compounds which may be used in the method are described in detail above with reference to the method for assaying for substances affecting TGF- $\beta$  cytokines. Conditions which permit the formation of cytokine-TGF- $\beta$  binding compound complexes may be selected having regard to factors such as the nature and amounts of the cytokine and the TGF- $\beta$  binding protein.

The following non-limiting examples are illustrative of the present invention:

EXAMPLES:

Example 1

The ability of fetuin and thyroglobulin to bind to and antagonize TGF- $\beta$  cytokines was tested.  $^3\text{H}$ -Thymidine incorporation in Mv1Lu cells, a mink lung epithelial line, was assessed in the presence of TGF- $\beta$ 1 (12 pM) alone, and with increasing concentrations of bovine fetuin (closed circles in Figure 1); bovine thyroglobulin (open triangles in Figure 1); or bovine serum albumin (closed triangles in Figure 1). Fetuin was also titrated into cultures of Mv1Lu cells in the absence (closed circles) or presence of cytokines; 18 pM human TGF- $\beta$ 1 (open squares), or 33 nM human BMP-2 (open triangles) (Figure 12).

Mv1Lu cells were seeded at 20,000 cells/well in a 96 well plate containing 0.2% FCS in  $\alpha$ -MEM and incubated with the indicated concentrations of proteins for 18 hr. The cells were then pulsed with 8  $\mu\text{Ci/ml}$  methyl- $^3\text{H}$ -thymidine (NEN, Boston, Ma) for 6 hr. Cells were trypsinized, harvested onto filtermats and counted in a  $\beta$ -Counter. Percent neutralization is defined as incorporation in the presence of 12 pM TGF- $\beta$ 1 alone set at 0%, and incorporation without additions as 100%. The difference in  $^3\text{H}$ -thymidine incorporation between 0% and 100% was 7.5 fold. Each point in Figure 1 and Figure 12 represents the mean of duplicate determinations, and the results are representative of three experiments. Bovine thyroglobulin and bovine fetuin



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(obtained by ammonium sulfate fractionation of FCS, followed by gel filtration chromatography) were purchased from Sigma (St. Louis, Mo.), BSA (fraction V) from Boehringer Mannheim (Laval, Quebec), and TGF- $\beta$ 1 (purified human) from Collaborative Research (Bedford, Ma.). Before use, bovine thyroglobulin was spun twice in a centricon (M.W. cutoff of 10,000 Da) micro-concentrator (Amicon, Beverly, MA) to remove any excess Iodine and T3/T4 thyroid hormones.

Figure 1 shows that bovine fetuin and bovine thyroglobulin neutralize the antiproliferative activity of TGF- $\beta$ 1 on cultures of Mv1Lu cells, a mink lung epithelial line which is highly sensitive to the anti-proliferative action of TGF- $\beta$ 1. Maximal effect for both fetuin and thyroglobulin was approximately 150% neutralization, suggesting that endogenous TGF- $\beta$  in the cultures is also inhibited resulting in a net stimulation of cell growth compared to controls. Similar observations have been reported for the TGF- $\beta$  antagonist decorin (Y. Yamaguchi, D. M. Mann, E. Ruoslahti, Nature 346, 281 (1990). S. Scholtz-Cherry J.E. Murphy-Ullrich, J. Cell Biol. 122, 923 (1993); O'Conner-McCourt, L.M. Wakefield J. Biol. Chem. 262, 14090 (1987); and, J. Massague Curr. Biol. 1, 117 (1991)).

Fetuin was able to inhibit the anti-proliferative activity of TGF- $\beta$ 1 on Mv1Lu cells in a dose dependent manner, with half-maximal inhibition ( $IC_{50}$ ) at  $4.2 \times 10^{-6}$  M. Thyroglobulin also neutralized TGF- $\beta$ 1 activity in the Mv1Lu growth inhibition assay with an  $IC_{50} = 2.2 \times 10^{-7}$  M (Figure 1). The  $IC_{50}$  for inhibition of TGF- $\beta$ 1 activity by thyroglobulin was 20 fold lower than for fetuin, a difference that is also reflected in the  $K_d$  values for association of TGF- $\beta$  with these glycoproteins (Table 1).

As shown in Figure 12, fetuin stimulated proliferation of Mv1Lu cells ( $IC_{50} = 8$  pM). Neutralizing antibody to TGF- $\beta$ 1 also stimulated cell proliferation, suggesting that Mv1Lu cells produce active TGF- $\beta$ , and cytokine antagonists can stimulate cell growth in the same

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manner as fetuin. Furthermore, fetuin blocked the anti-proliferative activity of exogenously-added TGF- $\beta$ 1, with an  $IC_{50}$  of approximately  $3 \times 10^{-6}$  M. BMP-2 also inhibited Mv1Lu cell growth ( $IC_{50} = 20$  nM), but at a much higher concentration than TGF- $\beta$ 1. Fetuin reversed the effect of BMP-2 with an  $IC_{50}$  of  $2-5 \times 10^{-6}$  M (Figure 12).

#### Example 2

To determine whether the action of fetuin as an antagonist of TGF- $\beta$ 1 in tissue culture was due to direct binding of the two proteins, their interaction by surface plasmon resonance using BIAcore (Pharmacia Biosensor, Piscataway, NJ) (M. Malmqvist, Nature 361, 186 (1993) and S. C. Schuster, R. V. Swanson, L. A. Alex, R. B. Bourret, M. I. Simon, Nature 365, 343 (1993)) was examined. In this system, a purified protein serving as the ligand is covalently coupled to a carboxymethylated dextran surface, and binding molecules (ie. the analyte) are passed in a fluid phase across the surface. Binding of the analyte to ligand causes a change in reflected light which is directly proportional to mass bound, and is measured in arbitrary response units (R.U.). Analyte-ligand binding is observed as both increasing response with time during the injection of analyte, and the difference in the position of the baseline before and after injection.

More particularly, purified human TGF- $\beta$ 1 (Collaborative Research, Bedford, Ma.) and recombinant human BMP-2 (a gift of Genetics Institute, Cambridge, Ma.) were immobilized onto the carboxy-methylated dextran surface of the CM5 sensor chip as described in M. Malmqvist, Nature 361, 186 (1993) and S. C. Schuster, R. V. Swanson, L. A. Alex, R. B. Bourret, M. I. Simon, Nature 365, 343 (1993). 1000 R.U. equals approximately 1 ng/mm<sup>2</sup>. The running buffer was 20 mM Hepes (pH7.2), 150mM NaCl and the flow rate for all sensorgrams was 3  $\mu$ l/min.

Fetal bovine fetuin (Sigma, Mo) and adult human fetuin/ $\alpha$ 2-HS glycoprotein (Calbiochem, Ca) were purified by the manufacturers using different protocols. Regeneration

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of the surface to remove bound analyte was done by injection of 10  $\mu$ l of 20 mM NaOH. To cyclize TRH1 peptides, the material was reduced with 5 mM DTT then brought to a final concentration of 60  $\mu$ M in 25 mM ammonium acetate (pH 8.5). After stirring in the dark for 30 min at 20°C with 30 mM potassium ferricyanide, the peptide was mixed with AG3-X4A resin (BioRad), filtered, lyophilization and desalted on a 50 x 2.5 cm column of Biogel P2 (Pharmacia) developed in water, and further purified by reverse phase HPLC. Ion spray mass spectroscopy confirmed cyclization and lack of peptide cross-linking.

Injection volumes were 36  $\mu$ l for Figure 2, 4 and 5 and 45  $\mu$ l for Figure 3. Regeneration of the surface to remove bound analyte was done by injecting 10  $\mu$ l of 1 M glucose-6-phosphate, or 1  $\mu$ l of 20 mM NaOH for TGF- $\beta$ 1 and BMP-2 coated-surfaces, respectively. Protein concentrations in each experiment were (Figures 2 and 3), 2, 5, 10, 20, 30, 40  $\mu$ M; (Figure 4), 0.21, 0.31, 0.41, 0.62, 0.82, 1.24  $\mu$ M; (Figure 5), 0.22, 0.29, 0.44, 0.59, 0.88  $\mu$ M. R.U. for the immobilized cytokine in each experiment was 2850 R.U. for Figures 2 and 3; 7450 R.U. for Figure 4, and 5300 R.U., for Figure 5 respectively.

The sensorgram overlay plots in Figures 2 to 5 show bovine fetuin binding in response units (R.U.) to immobilized TGF- $\beta$ 1 (Figure 2); and to immobilized BMP-2 (Figure 4). Each line from bottom to top represents increasing concentrations of injected analyte as detailed below. Figures 3 and 5 show the non-binding controls human transferrin passed over immobilized TGF- $\beta$ 1 and BSA passed over immobilized BMP-2, respectively. The large change in response at the beginning and end of injection is due to the change in refractive index caused by the protein in the injected buffer and does not indicate binding. Fetuin binding to TGF- $\beta$ 1 and BMP-2 is indicated by i) the increasing response with time during the injection, and ii) injection of increasing fetuin concentrations results in an incremental increase in response after the end of each

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injection. The fetuin-BMP-2 interaction shown in Figure 4 does not come to equilibrium, whereas in Figure 2 the lower affinity fetuin-TGF- $\beta$ 1 binding does come to equilibrium. Equilibrium is attained when the change in response with time is zero, as seen in panel (A) after approximately 200 seconds of fetuin binding to TGF- $\beta$ 1. Another control experiment showed that fetuin did not bind when a non-specific protein was immobilized (data not shown).

Binding constants for fetuin, thyroglobulin, and TRH1 peptides with TGF- $\beta$ 1 and BMPs were determined. Data was analyzed using the BIA-evaluation software (Pharmacia Biosensor). The association rate constant,  $k_{\text{ass}}$ , was calculated by first plotting the change in response with time versus response (ie.  $dR/dT$  vs  $R$ ). When the slope of the line from this graph is plotted versus analyte concentration (i.e.  $d(dR/dT)/dR$  vs  $C$ ),  $k_{\text{ass}}$  is obtained from the slope of the line. The dissociation rate constant,  $k_{\text{diss}}$ , is obtained during the decrease in response with time after analyte injection is discontinued. Specifically,  $k_{\text{diss}}$  was obtained from the slope of the line in a plot of  $\ln(R_{t1}/R_{tn})$  vs time. The affinity constants were calculated from  $K_D = k_{\text{diss}}/k_{\text{ass}}$ . Variance for  $k_{\text{ass}}$  is standard error of the linear regression plot, and for  $k_{\text{diss}}$  values are the mean  $\pm$  range of 3 or more independent injections. Steady state was observed for fetuin TGF- $\beta$ 1 binding, and analysis of these data by Scatchard plots produced a similar  $K_D$  value,  $4.6 \times 10^{-6}$  M. Tables 1 shows the binding constants for fetuin, thyroglobulin, TRH1b etc. interactions with cytokines. The calculations were repeated for fetuin and TRH1 binding to TGF- $\beta$  cytokines, and the calculations are set out in Table 2. Bracketed numbers in Tables 1 and 2 are percent homology of the cytokines relative to BMP-2.

Analysis of the non-equilibrium binding data revealed an association rate ( $k_{\text{ass}}$ ) for fetuin - TGF- $\beta$ 1 binding of  $670 \text{ M}^{-1}\text{s}^{-1}$  and dissociation rates ( $k_{\text{diss}}$ ) of  $1.6 \times 10^{-3} \text{ s}^{-1}$  (Table 1) and  $1.9 \times 10^{-3}$  (Table 2). Using the data in Figure 2, Scatchard type analysis for steady-state fetuin-

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TGF- $\beta$ 1 binding produced a  $K_D$  value of  $4.6 \times 10^{-6}$  M (data not shown), and the values  $2.2$  and  $2.4 \times 10^{-6}$  M (Table 1 and Table 2, respectively) were obtained from  $K_D = k_{\text{diss}}/k_{\text{ass}}$ . This measure of fetuin-TGF- $\beta$ 1 affinity is similar to the  $IC_{50}$  for fetuin neutralization of TGF- $\beta$ 1 activity (Figures 1 and 12), and is consistent with the view that fetuin neutralizes TGF- $\beta$ 1 activity by binding directly to the cytokine. Fetuin bound to the closely related cytokine TGF- $\beta$ 2, with similar affinity (Table 1 and Table 2).

Fetuin also bound to immobilized BMP-2 (Figure 4), a TGF- $\beta$  superfamily-member with 38% amino acid sequence identity to TGF- $\beta$ 1 (J. M. Wozney, V. Rosen, A. J. Celeste, L. M. Mitsock, M. J. Whitters, et al, Science 242, 1528 (1988) and V. Rosen, R. S. Thies, TIG 8, 97 (1992)). The affinity of fetuin binding to BMP-2 was approximately 100 times greater ( $K_D = 3.6 \times 10^{-8}$  M, and  $K_D = 2.7 \times 10^{-8}$  M, Table 1 and Table 2, respectively) than fetuin binding to TGF- $\beta$ 1. Both interactions showed a similar on-rate ( $k_{\text{ass}} = 1.7 \times 10^3 \text{ M}^{-1}\text{s}^{-1}$ ) but fetuin - BMP-2 had a much slower off-rate ( $k_{\text{diss}} = 6.2 \times 10^{-5} \text{ s}^{-1}$  (Table 1) and  $k_{\text{diss}} = 6.5 \times 10^{-5}$  (Table 2)), accounting for most of the difference in affinity. Fetuin also bound to immobilized BMP-4 and BMP-6 with characteristic affinities that differed largely due to changes in off-rates (Table 1 and Table 2). It is interesting to note that affinities for fetuin binding to the five cytokines showed a direct correlation with amino acid homology to BMP-2, the cytokine with the highest affinity for fetuin (Table 1 and Table 2). The rank order of  $K_D$ s measurements for fetuin-cytokine binding were BMP-2 < BMP-4 < BMP-6 < TGF- $\beta$ 1 < TGF- $\beta$ 2, which correlates with their primary sequence homology to BMP-2 (Table 1 and Table 2).

Thyroglobulin was also tested for binding to the BMPs and TGF- $\beta$  in the BIAcore assay described above. Surprisingly, thyroglobulin bound with higher affinity than fetuin to the cytokines, showing the strongest interaction with BMP-2 ( $K_D = 3.1 \times 10^{-9}$  M). Thyroglobulin bound to BMP-2

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> BMP-4 > TGF- $\beta$ 1 > TGF- $\beta$ 2, a rank order similar to that observed for fetuin binding to these cytokines (Table 1 and Table 2). Thyroglobulin is found at low levels in serum, and at much higher concentrations in the follicles of the thyroid where it is a precursor to thyroxine. TGF- $\beta$  has been shown to inhibit thyroglobulin biosynthesis and thyroid cell proliferation in vitro (Colletta et al. Cancer Res. 49, 3457, 1989). In this context, the results of the present studies suggest that thyroglobulin may bind to and antagonize this action of TGF- $\beta$  in the thyroid.

### Example 3

The amino acid sequences of fetuin and TGF- $\beta$  receptor type I or type II were compared to identify a cytokine-binding domain. The fetuin and T $\beta$ RII sequences were first aligned by positioning of the cysteine residues. The TGF- $\beta$  type I (Tsk 7L) receptor shown in Figure 8 is aligned with T $\beta$ RII as in H. Y. Lin, X. -F. Wang, E. Ng-Eaton, R. A. Weinberg, H. F. Lodish, Cell 68, 775 (1992). The TGF- $\beta$  type I (Tsk 7L) receptor shown in Figure 8 is aligned with T $\beta$ RII as in Ebner et al. Science 260, 1344-1348, 1993. Visual examination of the alignment revealed the 43 amino acid homology domain designated TGF- $\beta$  Receptor II Homology 1 domain (TRH1) (Figure 8). The TRH1 domain is present in T $\beta$ RII, ActRII and ActRIIb, but absent in the type I receptors (Lin et al., Cell 68, 775-785, 1992; Ebner et al., Science 260, 1344-1348, 1993; Attisano et al., Cell 75, 671-680, 1993; Franzen et al., Cell 75, 681-692, 1993; Bassing et al., Science 263, 87-89, 1994) which do not bind cytokines in the absence of type II receptors (Wrana et al., Cell 71, 1003-1014, 1992; Wrana et al., Nature 370, 341-347 1994). The intramolecular disulfide bonds of human fetuin have previously been determined (J. Kellermann, H. Haupt, E. -A. Auerswald, W. Müller-Esterl, J. Biol. Chem 264, 14121 (1989)). The TRH1 domain in fetuin forms a peptide loop in the amino end structural duplication. The structural duplications are indicated as

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the larger semi-circles in Figure 7, and are designated a and b (Figures 7 and 8).

As shown in Figure 7, each structural duplication in fetuin contains two disulphide loops, including the TRH1 domain (position 114-132), and the inactive loop2 (ie position 230-248). TM and kinase indicate transmembrane domain and protein-kinase domains of T $\beta$ RII, respectively. The Chou-Fasman (Chou and Fasman, 1978) and Garnier, Osguthorpe, and Robson (Garnier et al., 1978) methods of predicting secondary structure produced similar results for the TRH1 domain of fetuin and T $\beta$ RII as indicated below the sequences in Figure 7.

Algorithms for secondary-structure predict a  $\beta$ -sheet-turn- $\beta$ -sheet arrangement for the TRH1 peptides of fetuin, T $\beta$ RII and the type II activin receptors, but this structure is not predicted for loop2, the analogously-positioned loop in the carboxy end of fetuin (Figure 7). Low-ultraviolet CD spectra of the cyclized TRH1 peptides preformed indicates the presence of 58%  $\beta$ -sheet, 41% random coil consistent with the prediction algorithm (Figure 13).

The TRH1 domain and flanking sequences in fetuin are highly conserved across species (ie. human, bovine, sheep, rat, mouse)(Dziegielewska et al., J. Biol. Chem. 265, 4354-4357 1990; Rauth et al., J. Biochem. 204, 523-529, 1992; lee et al., Proc. Natl. Acad. Sci. USA 84, 4403-4407 1987; Brown et al., Eur. J. Biochem. 321-331 1992), relative to the carboxy half of the molecule (See Figure 6). Indeed, human fetuin ( $\alpha$ 2-HS glycoprotein) bound to BMP-2 with similar affinity as that of bovine fetuin (data not shown).

A search of the PIR protein sequence data bank for other proteins containing the TRH1 domain was conducted using the GCG routine "findpatterns" and the following pattern: CX{8,14} (N,Q)X{12,16}CX{4,5} (K,R) X {2,6} (S,T)X{4,9} CX{0,2}DX{5,6}(D,E). The pattern was based on conserved amino acids between fetuin, T $\beta$ RII, daf-1, and activin receptor type II. The search yielded 46 matches, most of which were extracellular domains of receptors or

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secreted glycoproteins and included, fetuins (n=5), kinnogens which are distant family members of the fetuins (J. Kellermann, H. Haupt, E. -A. Auerswald, W. Müller-Esterl, J. Biol. Chem 264, 14121 (1989)) (n=5), daf-1 (n=1), activin receptor type II (n=5), bovine thyroglobulin (L. Mercken, M. -J. Simons, S. Swillons, M. Massaer, G. Vassart, Nature 316, 647 (1985)) (n=1), EGF receptor (n=2), LDL receptor (n=1), IL-1 receptor (n=1) and drosophila crumbs (n=1). The number in brackets indicates the number of matches; for example fetuin from 5 species.

A low stringency search of the PIR protein data bank was also done using conserved residues in the TRH1 domains of fetuin and the type II receptors for TGF- $\beta$  and activin was performed. The GCG routine "findpatterns" and the following pattern were used: CX{0,1}(V,I,F,Y)X{1,3}(V,W,L)X{0,1}(K,R)X{4,5}(V,I,F)X{1,2}(L,I)X{2,4}CX{0,2}D. The search yielded 32 matches, 25 of which represented fetuin (n=5), T $\beta$ R11 (n=2), and type II activin receptors (n=18) from various species.

Similarity in sequence between the TRH1b subdomains of T $\beta$ R11, fetuin and thyroglobulin was striking, ranging from 63% to 71% (Figure 8). Therefore, thyroglobulin was tested for binding to the BMPs and TGF- $\beta$  in the BIAcore assay as described in Examples 1 and 2.

#### Example 4

The TGF- $\beta$  and activin type I receptors lack the TRH1b sequence (Figure 8), and do not bind ligand in the absence of type II receptors (R. Ebner, R. -H. Chen, L. Shum, S. Lawler, T. F. Zioncheck, et al, Science 260, 1344 (1993); L. Attisano, J. Carcamo, F. Ventura, F. M. B. Weis, J. Massague, et al, Cell 75, 671 (1993); P. Franzen, P. ten Dijke, H. Ichijo, H. Yamashita, P. Schulz, et al, Cell 75, 681 (1993); C. H. Bassing, J. M. Yingling, D. J. Howe, T. Wang, W. W. He, et al, Science 263, 87 (1994); and J. L. Wrana, L. Attisano, J. Carcamo, A. Zentella, J. Doody, et al, Cell 71, 1003 (1992)). This suggested that the TRH1b subdomain of type II receptors may be directly involved in



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cytokine binding. To examine this possibility, TRH1b peptides from both fetuin and T $\beta$ R1I were synthesized and a cyclized TRH1b peptide was prepared. The TRH1 peptides and cyclized peptide were tested for binding to TGF- $\beta$ 1 and BMP-2.

The cyclized TRH1b peptide was prepared by first reducing the peptide with DTT to remove dimers, trimers etc. and then bringing to a final concentration of 60  $\mu$ M in 25 mM ammonium acetate (pH 8.5). After stirring in the dark for 30 min at 20°C with 30 mM potassium ferricyanide, the peptide was mixed with AG3-X4A resin (BioRad) and filtered. Following lyophilization, the sample was desalted on a 50 x 2.5 cm column of Biogel P2 (BioRad) developed in water. Ion spray mass spectroscopy confirmed cyclization and did not detect the presence of multimers. Peptide, in 0.15 M Tris pH 8.0, 0.15 M NaCl, 2 mM EDTA, was reduced and alkylated by first boiling in 90 fold excess DTT for 10 min., followed by a 15 min incubation with 45 fold excess iodoacetamide (Pierce) in the dark with shaking. The sample was desalted on a P2 column. Ion spray mass spectroscopy confirmed reduction and alkylation of the peptide.

Figure 9 is a sensorgram overlay plot displaying binding of the disulfide-looped TRH1b fetuin peptide to immobilized BMP-2 (5300 R.U. immobilized) at 6 concentrations (87, 130, 174, 217, 283, and 348  $\mu$ M). Figure 10 is a sensorgram plot showing the lack of binding of reduced and alkylated TRH1b peptide at the same concentrations. As the BIAcore signal measures mass, the lower molecular weight TRH1b peptide made it necessary to use near-saturating binding conditions to observe signal. Saturation was determined to be approximately 550 R.U. Competition of fetuin- BMP-2 binding by cyclized TRH1b peptide was observed, and to a much lesser extent, by the reduced and alkylated peptide (data not shown). Since TRH1b peptide is 1/20 the mass of fetuin, and therefore gives proportionately less signal per molecule bound, a reduction in response was observed when low concentrations of TRH1b

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were co-injected with fetuin, compared to fetuin alone. However, it was not possible to separate in a quantitative manner, the fetuin and TRH1b peptide BIAcore signals observed with the non-equilibrium conditions experienced in these experiments.

The results demonstrate that the intramolecular disulfide-looped form of the fetuin TRH1b peptide bound directly to immobilized BMP-2 with a  $K_D = 3.2 \times 10^6$  M (Figure 9, Table 1) and a  $K_D = 2.4 \times 10^6$  M (Table 2), and also competed for fetuin-BMP-2 binding in a dose dependent manner. However, no significant binding to BMP-2 was observed when this peptide was reduced and alkylated (Figure 9). This is consistent with the observation that reduced and alkylated fetuin had diminished binding to BMP-2 and TGF- $\beta$ 1 compared to native fetuin (data not shown). This suggests that disulphide-looping stabilizes a preferred TRH1 peptide structure for cytokine binding. The on-rate for disulfide-looped TRH1b peptide binding to BMP-2 is similar to that for intact fetuin, whereas the off-rate of TRH1b is 100 times faster (Table 1 and Table 2). This suggests that the TRH1b domain in fetuin is the major peptide motif involved in the initial recognition and binding to cytokine. Other portions of the fetuin protein may stabilize binding and/or the conformation of the TRH1b peptide loop, thereby slowing fetuin's off-rate when compared with the peptide.

If cytokine binding to T $\beta$ RII is mediated by the TRH1b sequence, the known cytokine specificity of the receptors (J. L. Wrana, L. Attisano, J. Carcamo, A. Zentella, J. Doody, et al, Cell 71, 1003 (1992)) predicts that the peptide sequence from T $\beta$ RII should bind to TGF- $\beta$ 1 with higher affinity than to BMP-2. BIAcore binding data confirmed this prediction (See Example 5 and Table 1, and Table 2). The cyclized T $\beta$ RII peptide bound to TGF- $\beta$ 1 with higher affinity than to BMP-2 (ie.  $K_D = 5.2 \times 10^{-7}$  M and  $>10^{-5}$ , respectively), a reversal of binding preference shown by the TRH1b peptide from fetuin (Table 1 and Table 2). This

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suggests that the TRH1b sequences can dictate ligand binding affinities and therefore ligand specificity.

Example 5

Competition of TGF- $\beta$ 1 binding to immobilized  
5 T $\beta$ R11 using fetuin and looped TRH1 peptide from T $\beta$ R11.

Inhibition of TGF- $\beta$ 1 binding to T $\beta$ R11 was carried out using the Quantikine ELISA kit (R&D Systems). In particular, 96 well plates were pre-coated with the extracellular domain of T $\beta$ R11. To study competition of  
10 TGF- $\beta$ 1 binding, the cytokine was brought to a final concentration of 40 pM in diluent provided with the kit, either alone or with antagonists fetuin (40  $\mu$ M), TRH1 peptide from T $\beta$ R11 (20  $\mu$ M) or BSA (40  $\mu$ M) for 1.5 hr at 20°C in siliconized Eppendorf tubes with shaking. This was  
15 followed by a 5 minute incubation with the T $\beta$ R11 coated ELISA wells with shaking, washing as recommended, and a 1 hr incubation with the polyclonal anti-TGF- $\beta$ 1 antibody. Plates were developed as per the instructions, and determinations were made in triplicate. Figure 14 shows  
20 that the TRH1b peptide and fetuin serve as competitive inhibitors of TGF- $\beta$ 1 binding to immobilized recombinant T $\beta$ R11. Therefore, TRH1b appears to be the primary recognition site in T $\beta$ R11, and sequence differences amongst the TRH1b domains of type II receptors and fetuin may  
25 largely dictate cytokine specificity.

The experiments described in the above Examples define a disulfide-looped motif common to T $\beta$ R11, fetuin and thyroglobulin which mediates binding to two divergent members of the TGF- $\beta$  superfamily. The TRH1 motif is  
30 conserved in the ligand-binding T $\beta$ R11 family members including activin type II<sup>18</sup> and daf-1 receptors, but is absent in the TGF- $\beta$ /activin type I receptors; the latter are unable to bind cytokine in the absence of type II receptors. Fetuin and thyroglobulin have significantly  
35 higher affinities for BMP-2 than for TGF- $\beta$ 1, suggesting that variations in both TGF- $\beta$ s and TRH1 sequences may dictate ligand -receptor/antagonist specificity through

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changes in binding-affinity. The results also suggest a hitherto unknown function for fetuin and thyroglobulin as antagonists of TGF- $\beta$  superfamily members *in vivo* and may explain the mechanism for the broad biological activities ascribed to fetuin.

#### Example 6

The methods used in the studies described in this example and illustrated in Figures 16 and 17 are as follows. Femoral bones were removed under aseptic conditions from adult male Wistar rats (120 g), cleaned of adherent soft tissues, and washed extensively in antibiotics. The distal ends were removed and the marrow contents were flushed out with 10 ml of culture medium. The cells were dispersed by repeated passage through a 20 gauge needle and incubated in alpha-MEM supplemented with 15% fetal bovine serum, ascorbic acid (50  $\mu\text{g/ml}$ ), antibiotics (penicillin G 100  $\mu\text{g/ml}$ , gentamicin 50  $\mu\text{g/ml}$ , fungizone 0.3  $\mu\text{g/ml}$ ) and 10 mM  $\beta$ -glycerophosphate. The culture media were supplemented further with dexamethasone alone ( $10^{-8}\text{M}$ ), or with the various concentrations of fetuin. Following 6 days of culture at  $37^\circ\text{C}$  in a humidified atmosphere containing 5%  $\text{CO}_2$  in air, the cells were replated at a density of  $1 \times 10^2$  cell/ $\text{mm}^2$  in 96 multi-well plates (Falcon 3047), and grown for another 12-14 days. At the end of culture, the cells were fixed and stained for calcium with alizarin red-s for quantification of bone nodule area (reported as mineralized area ( $\text{mm}^2$ )/well). To assess mineralized tissue formation in the cultures morphometric measurements were carried out with the aid of a Bioquant IV system (Bioquant, Nashville, TN, USA) using a Leitz Orthoplan microscope. TGF- $\beta$  in culture supernatants taken 4 days prior to scoring mineralization were measured with and without heat activation ( $80^\circ\text{C}$  for 10 min) using the Mink cells as the indicator cell line as described in Figure 12. Neutralizing anti-TGF- $\beta$  antibodies supplied by R&D systems were specific for TGF- $\beta 1$  and with 100 fold lower reactivity for TGF- $\beta 2$  and  $\beta 3$ .

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With fetuin's greater affinity for BMPs, as well as co-localization of fetuin and BMPs in developing bone (Rosen and Thies, *Trends Genet.* 8, 97-102, 1992; Wozney et al., *Science* 242, 1528-1534, 1988), fetuin-cytokine interactions may play a role in bone cell differentiation. To examine this possibility, rat bone marrow stromal cells were cultured in the presence of dexamethasone which induces osteogenic differentiation with deposition of calcium-containing matrix after three weeks of culture (Figures 15 to 18). The addition of exogenous TGF- $\beta$  at an early stage of culture inhibits cell proliferation (Oursler et al., *Endocrinology* 133, 2187-2196 1993), but in the latter phase of osteogenic differentiation, the cytokine is necessary for deposition of matrix (Van Vlasselaer et al., *J. Cell Biol.* 4, 569-577, 1994). During the first week of culture, which is the proliferative phase, the addition of fetuin stimulated an increase in cell number, consistent with its role as a TGF- $\beta$  antagonist (Figure 15). When added during the latter two weeks of culture, fetuin inhibited deposition of calcium-containing matrix, also as expected of a TGF- $\beta$  antagonist (Figure 16). The  $IC_{50}$  for inhibition of calcium-deposition was approximately  $10^{-5}M$ , a concentration only 5 fold greater than the BIAcore measurement of  $K_d$  for fetuin-TGF- $\beta$  binding. Since fetuin is present in the 15% FCS of the culture medium at concentrations of  $2-3 \times 10^5$ , this represents only a 30-50% increase in fetuin concentrations. Dexamethasone increased TGF- $\beta$  levels in the rat bone marrow cultures by inducing activation of latent cytokine (Figure 17). Although total cytokine levels remained similar, the fraction of active TGF- $\beta$  increased 3 fold in dexamethasone-treated cultures. Data in Figure 18 shows that neutralizing anti-TGF- $\beta$  antibodies alone, or in combination with fetuin completely block deposition of calcium-containing matrix in the dexamethasone-treated bone marrow cultures. This confirms the requirement for TGF- $\beta$  to complete the final stages of differentiation, but does not exclude the involvement of

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other TGF- $\beta$  family members. The suppressive effect of fetuin on deposition of calcium-containing matrix is not likely due to cytotoxicity, as marrow cell proliferation was stimulated by fetuin during the first week of culture (Figure 16). BMP-2 also induced osteogenesis in these cultures which could be blocked by the addition of fetuin (data not shown).

In summary, the above experiments define a disulphide-looped motif present in T $\beta$ R $\beta$ II and fetuin which mediates binding to multiple members of the TGF- $\beta$  superfamily. The TRH1 motif is also found in the activin type II receptors (Mathews and Vale, 1991), but is absent in type I cytokine receptors (Ebner et al., 1993; Attisano et al., 1993; Franzen et al., 1993; Wrana et al., 1992). The results also indicate a hitherto unknown function for fetuin as an antagonist of TGF- $\beta$  superfamily members *in vivo*, and may explain the mechanism for the various biological activities previously ascribed to fetuin (Nie, *Am. J. Med.*, 1994). Most notably, fetuin via the circulation accumulates in bone (Dickson et al., *Nature* 256, 430-432 1975; Triffitt et al., *Nature* 262, 226-227, 1976), with highest concentrations found at locations of bone growth, where it may regulate the bone promoting activity of BMPs (Wozney et al., *Science* 242, 1528-1534, 1988; Rosen and Thies, 1992) and TGF- $\beta$ s (Massagué, 1990). In Paget's disease an affliction of increased bone turnover with disordered and thickened bone, serum fetuin levels are depressed, whereas fetuin is elevated in a subset of osteogenesis imperfecta patients. Finally, cytokine antagonists based on the TRH1b peptide would appear to be useful in the treatment of immune suppression in cancer patients and fibrotic disorders (Massagué, 1990), such as glomerulonephritis (Border et al., *Nature* 360, 361-364, 1992) and atherosclerosis (Ross, *Nature* 362, 801-809, 1993) where elevated cytokine activity are known to play a role (Border and Ruoslahti, *J. Clin. Invest.* 90, 1-7, 1992).

The present invention has been described in

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detail and with particular reference to the preferred embodiments; however, it will be understood by one having ordinary skill in the art that changes can be made thereto without departing from the spirit and scope thereof.

5 All publications, patents and patent applications referred to herein, are herein incorporated by reference in their entirety to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated by reference  
10 in its entirety.

Forming part of the present disclosure are the appended sequence listings.

Table 1  
Binding constants for fetuin, thyroglobulin and TRH1b interactions with cytokines

Analyte	Ligand	$k_{on}$ ( $M^{-1}s^{-1}$ )	$k_{off}$ ( $s^{-1}$ )	$K_D$ (M)
Fetuin	TGF- $\beta$ 1 (38%)	$6.7 \times 10^3 \pm 4.0 \times 10^3$	$1.6 \times 10^3 \pm 0.4 \times 10^3$	$2.4 \times 10^{-6}$
	TGF- $\beta$ 2 (36%)	$5.5 \times 10^3 \pm 1.2 \times 10^3$	$3.2 \times 10^3 \pm 0.5 \times 10^3$	$5.8 \times 10^{-6}$
	BMP-2 (100%)	$1.7 \times 10^3 \pm 0.3 \times 10^3$	$6.2 \times 10^3 \pm 3.6 \times 10^3$	$3.6 \times 10^{-6}$
	BMP-4 (86%)	$4.2 \times 10^3 \pm 0.2 \times 10^3$	$5.8 \times 10^4 \pm 0.1 \times 10^4$	$1.4 \times 10^{-7}$
	BMP-6 (57%)	$2.9 \times 10^3 \pm 0.5 \times 10^3$	$2.5 \times 10^3 \pm 0.5 \times 10^3$	$8.6 \times 10^{-7}$
Thyroglobulin	TGF- $\beta$ 1	$2.8 \times 10^3 \pm 1.0 \times 10^3$	$1.9 \times 10^3 \pm 0.8 \times 10^3$	$6.8 \times 10^{-7}$
	TGF- $\beta$ 2	$1.3 \times 10^3 \pm 0.6 \times 10^3$	$5.0 \times 10^3 \pm 0.5 \times 10^3$	$3.8 \times 10^{-6}$
	BMP-2	$3.2 \times 10^4 \pm 0.2 \times 10^4$	$1.0 \times 10^4 \pm 0.1 \times 10^4$	$3.1 \times 10^{-9}$
	BMP-4	$5.4 \times 10^4 \pm 0.7 \times 10^4$	$1.1 \times 10^3 \pm 0.4 \times 10^3$	$2.0 \times 10^{-6}$
TRH1b (fetuin) (reduced & alkylated)	BMP-2	$1.6 \times 10^3 \pm 0.5 \times 10^3$	$5.1 \times 10^3 \pm 1.1 \times 10^3$	$3.2 \times 10^{-6}$
	TGF- $\beta$ 1	--	--	$> 10^{-3}$
TRH1b (T $\beta$ RII) (reduced & alkylated)	BMP-2	--	--	$> 10^{-3}$
	TGF- $\beta$ 1	$3.7 \times 10^3 \pm 2.9 \times 10^3$	$1.9 \times 10^3 \pm 0.5 \times 10^3$	$5.2 \times 10^{-7}$
	TGF $\beta$ 1	--	--	$> 10^{-3}$

Binding constants for fetuin, thyroglobulin and TRH1b peptides with TGF- $\beta$  and BMPs. Data was analyzed using the BIA-evaluation software (Pharmacia Biosensor). The association rate constant,  $k_{on}$ , was calculated by first plotting the change in response with time versus response (ie.  $dR/dT$  vs  $R$ ). When the slope of the line from this graph is plotted versus analyte concentration (ie.  $d(dR/dT)/dR$  vs  $C$ ),  $k_{on}$  is obtained from the slope of the line. The dissociation rate constant,  $k_{off}$ , is obtained during the decrease in response with time after analyte injection is discontinued. Specifically,  $k_{off}$  was obtained from the slope of the line in a plot of  $\ln(R_t/R_{eq})$  vs time. The affinity constants were calculated from  $K_D = k_{off}/k_{on}$ . Variance for  $k_{on}$  is standard error of the linear regression plot, and for  $k_{off}$  values are the mean  $\pm$  range of 3 or more independent injections. Bracketed numbers are percent homology of the cytokines relative to BMP-2.



Table 2

Fetuin and TRH1 binding to TGF- $\beta$  cytokines

Analyte	Ligand	$k_{on}$ ( $M^{-1}s^{-1}$ )	$k_{off}$ ( $s^{-1}$ )	$K_D$ (M)
b-Fetuin	TGF- $\beta$ 1 (38%)	$8.7 \times 10^3 \pm 2.7 \times 10^2$	$1.9 \times 10^{-3} \pm 0.6 \times 10^{-3}$	$2.2 \times 10^{-6}$
	TGF- $\beta$ 2 (36%)	$5.5 \times 10^3 \pm 1.2 \times 10^2$	$2.4 \times 10^{-3} \pm 0.3 \times 10^{-3}$	$4.4 \times 10^{-6}$
	BMP-2 (100%)	$2.4 \times 10^3 \pm 1.2 \times 10^2$	$6.5 \times 10^{-3} \pm 2.1 \times 10^{-3}$	$2.7 \times 10^{-6}$
	BMP-4 (86%)	$4.2 \times 10^3 \pm 0.2 \times 10^3$	$5.1 \times 10^{-4} \pm 0.1 \times 10^{-4}$	$1.2 \times 10^{-7}$
	BMP-6 (57%)	$2.9 \times 10^3 \pm 0.5 \times 10^3$	$2.1 \times 10^{-3} \pm 0.3 \times 10^{-3}$	$7.1 \times 10^{-7}$
h-Fetuin	BMP-2	$2.2 \times 10^4 \pm 0.5 \times 10^4$	$1.1 \times 10^{-3} \pm 0.1 \times 10^{-3}$	$5.1 \times 10^{-6}$
TRH1 (b-fetuin)	BMP-2	$1.3 \times 10^3 \pm 0.5 \times 10^3$	$3.8 \times 10^{-3} \pm 0.5 \times 10^{-3}$	$2.4 \times 10^{-6}$
(reduced)	TGF- $\beta$ 1	--	--	$> 10^{-5}$
loop2 (b-fetuin)	BMP-2	--	--	$> 10^{-5}$
TRH1 (T $\beta$ RII)	BMP-2	--	--	$> 10^{-5}$
(reduced)	TGF- $\beta$ 1	$2.2 \times 10^3 \pm 1.3 \times 10^3$	$2.3 \times 10^{-3} \pm 0.5 \times 10^{-3}$	$1.0 \times 10^{-6}$
	TGF- $\beta$ 1	--	--	$> 10^{-5}$

Binding constants for fetuins and TRH1 peptide interactions with TGF- $\beta$  and BMPs measured using the BIAcore and BIA-evaluation software (Pharmacia Biosensor). The change in response with time was plotted for each analyte concentration (ie.  $dR/dT$  vs  $R$ ), and the slope of these lines were then plotted as a function of analyte concentration (ie  $d(dR/dT)/dR$  vs  $C$ ), where the slope yields  $k_{on}$ . The dissociation rate constant,  $k_{off}$ , is obtained after analyte injection is discontinued as the slope of  $\ln(R_t/R_\infty)$  vs time.  $K_D$ s are  $k_{off}/k_{on}$ . Variance for  $k_{on}$  is standard error of the linear regression plot, and for  $k_{off}$  values are the mean  $\pm$  range of 3 or more independent injections. Steady-state was observed for fetuin - TGF- $\beta$ 1 binding, and analysis of these data by Scatchard plots produced a similar  $K_D$  value,  $4.6 \times 10^{-6}$  M. Bracketed numbers are percent homology of the cytokines relative to BMP-2. Methods. TGF- $\beta$ s and BMPs were immobilized onto the carboxy-methylated dextran surface of the CM5 sensor chip. 1000 R.U. equals approximately 1 ng/ $\mu m^2$ . The running buffer was 20 mM Hepes (pH 7.2), 150 mM NaCl and the flow rate was 3  $\mu l/min$ . Bovine fetal fetuin (Sigma, Mo) and adult human fetuin/ $\alpha$ 2-HS glycoprotein (Calbiochem, Ca) were purified by the manufacturers using different protocols. Regeneration of the surface to remove bound analyte was done by injecting of 10  $\mu l$  of 20 mM NaOH. To cyclize TRH1 peptides, the material was reduced with 5 mM DTT then brought to a final concentration of 60  $\mu M$  in 25 mM ammonium acetate (pH 8.5). After stirring in the dark for 30 min at 20°C with 30 mM potassium ferricyanide, the peptide was mixed with AG3-X4A resin (BioRad), filtered, lyophilization and desalted on a 50 x 2.5 cm column of Biogel P2 (Pharmacia) developed in water, and further purified by reverse phase HPLC. Ion spray mass spectroscopy confirmed cyclization and lack of peptide cross-linking.

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## SEQUENCE LISTING

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(E) COUNTRY: Canada  
(F) POSTAL CODE (ZIP): M4Y 1R5

(ii) TITLE OF INVENTION: MODULATORS OF CYTOKINES OF THE TGF $\beta$  SUPERFAMILY AND METHODS FOR ASSAYING FOR SAME

(iii) NUMBER OF SEQUENCES: 7

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(E) COUNTRY: Canada  
(F) ZIP: M5H 3Y2

## (v) COMPUTER READABLE FORM:

(A) MEDIUM TYPE: Floppy disk  
(B) COMPUTER: IBM PC compatible  
(C) OPERATING SYSTEM: PC-DOS/MS-DOS  
(D) SOFTWARE: PatentIn Release #1.0, Version #1.25

## (vi) CURRENT APPLICATION DATA:

(A) APPLICATION NUMBER: PCT  
(B) FILING DATE:  
(C) CLASSIFICATION:

## (viii) ATTORNEY/AGENT INFORMATION:

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(B) REGISTRATION NUMBER: 34,971

(C) REFERENCE/DOCKET NUMBER: 3153-144

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## (2) INFORMATION FOR SEQ ID NO:1:

## (i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 567 amino acids

(B) TYPE: amino acid

(D) TOPOLOGY: unknown

## (ii) MOLECULE TYPE: peptide

## (vi) ORIGINAL SOURCE:

(A) ORGANISM: Homo sapiens

## (vii) IMMEDIATE SOURCE:

(A) LIBRARY: Lambda zapII

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

Met	Gly	Arg	Gly	Leu	Leu	Arg	Gly	Leu	Trp	Pro	Leu	His	Ile	Val	Leu
1				5				10						15	
Trp	Thr	Arg	Ile	Ala	Ser	Thr	Ile	Pro	Pro	His	Val	Gln	Lys	Ser	Val
			20					25					30		
Asn	Asn	Asp	Met	Ile	Val	Thr	Asp	Asn	Asn	Gly	Ala	Val	Lys	Phe	Pro
			35					40					45		
Gln	Leu	Cys	Lys	Phe	Cys	Asp	Val	Arg	Phe	Ser	Thr	Cys	Asp	Asn	Gln
			50					55					60		
Lys	Ser	Cys	Met	Ser	Asn	Cys	Ser	Ile	Thr	Ser	Ile	Cys	Glu	Lys	Pro
			65					70					75		80
Gln	Glu	Val	Cys	Val	Ala	Val	Trp	Arg	Lys	Asn	Asp	Glu	Asn	Ile	Thr
				85					90					95	
Leu	Glu	Thr	Val	Cys	His	Asp	Pro	Lys	Leu	Pro	Tyr	His	Asp	Phe	Ile
				100					105					110	
Leu	Glu	Asp	Ala	Ala	Ser	Pro	Lys	Cys	Ile	Met	Lys	Glu	Lys	Lys	Lys
				115					120					125	
Pro	Gly	Glu	Thr	Phe	Phe	Met	Cys	Ser	Cys	Ser	Ser	Asp	Glu	Cys	Asn
				130					135					140	
Asp	Asn	Ile	Ile	Phe	Ser	Glu	Glu	Tyr	Asn	Thr	Ser	Asn	Pro	Asp	Leu
				145					150					155	160

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Leu Leu Val Ile Phe Gln Val Thr Gly Ile Ser Leu Leu Pro Pro Leu  
 165 170 175  
 Gly Val Ala Ile Ser Val Ile Ile Ile Phe Tyr Cys Tyr Arg Val Asn  
 180 185 190  
 Arg Gln Gln Lys Leu Ser Ser Thr Trp Glu Thr Gly Lys Thr Arg Lys  
 195 200 205  
 Leu Met Glu Phe Ser Glu His Cys Ala Ile Ile Leu Glu Asp Asp Arg  
 210 215 220  
 Ser Asp Ile Ser Ser Thr Cys Ala Asn Asn Ile Asn His Asn Thr Glu  
 225 230 235 240  
 Leu Leu Pro Ile Glu Leu Asp Thr Leu Val Gly Lys Gly Arg Phe Ala  
 245 250 255  
 Glu Val Tyr Lys Ala Lys Leu Lys Gln Asn Thr Ser Glu Gln Phe Glu  
 260 265 270  
 Thr Val Ala Val Lys Ile Phe Pro Tyr Glu Glu Tyr Ala Ser Trp Lys  
 275 280 285  
 Thr Glu Lys Asp Ile Phe Ser Asp Ile Asn Leu Lys His Glu Asn Ile  
 290 295 300  
 Leu Gln Phe Leu Thr Ala Glu Glu Arg Lys Thr Glu Leu Gly Lys Gln  
 305 310 315 320  
 Tyr Trp Leu Ile Thr Ala Phe His Ala Lys Gly Asn Leu Gln Glu Tyr  
 325 330 335  
 Leu Thr Arg His Val Ile Ser Trp Glu Asp Leu Arg Lys Leu Gly Ser  
 340 345 350  
 Ser Leu Ala Arg Gly Ile Ala His Leu His Ser Asp His Thr Pro Cys  
 355 360 365  
 Gly Arg Pro Lys Met Pro Ile Val His Arg Asp Leu Lys Ser Ser Asn  
 370 375 380  
 Ile Leu Val Lys Asn Asp Leu Thr Cys Cys Leu Cys Asp Phe Gly Leu  
 385 390 395 400  
 Ser Leu Arg Leu Asp Pro Thr Leu Ser Val Asp Asp Leu Ala Asn Ser  
 405 410 415  
 Gly Gln Val Gly Thr Ala Arg Tyr Met Ala Pro Glu Val Leu Glu Ser  
 420 425 430  
 Arg Met Asn Leu Glu Asn Ala Glu Ser Phe Lys Gln Thr Asp Val Tyr  
 435 440 445  
 Ser Met Ala Leu Val Leu Trp Glu Met Thr Ser Arg Cys Asn Ala Val  
 450 455 460

- 50 -

Gly Glu Val Lys Asp Tyr Glu Pro Pro Phe Gly Ser Lys Val Arg Glu  
 465 470 475 480

His Pro Cys Val Glu Ser Met Lys Asp Asn Val Leu Arg Asp Arg Gly  
 485 490 495

Arg Pro Glu Ile Pro Ser Phe Trp Leu Asn His Gln Gly Ile Gln Met  
 500 505 510

Val Cys Glu Thr Leu Thr Glu Cys Trp Asp His Asp Pro Glu Ala Arg  
 515 520 525

Leu Thr Ala Gln Cys Val Ala Glu Arg Phe Ser Glu Leu Glu His Leu  
 530 535 540

Asp Arg Leu Ser Gly Arg Ser Cys Ser Glu Glu Lys Ile Pro Glu Asp  
 545 550 555 560

Gly Ser Leu Asn Thr Thr Lys  
 565

## (2) INFORMATION FOR SEQ ID NO:2:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 45 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: unknown

## (ii) MOLECULE TYPE: peptide

## (vi) ORIGINAL SOURCE:

- (A) ORGANISM: Homo sapiens

## (vii) IMMEDIATE SOURCE:

- (A) LIBRARY: lambda zapII

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Cys His Val Leu Asp Pro Thr Pro Leu Ala Asn Cys Ser Val Arg Gln  
 1 5 10 15

Gln Thr Gln His Ala Val Glu Gly Asp Cys Asp Ile His Val Leu Lys  
 20 25 30

Gln Asp Gly Gln Phe Ser Val Leu Phe Thr Lys Cys Asp  
 35 40 45

## (2) INFORMATION FOR SEQ ID NO:3:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 43 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: unknown

## (ii) MOLECULE TYPE: peptide

- 51 -

(vi) ORIGINAL SOURCE:  
 (A) ORGANISM: Homo sapiens

(vii) IMMEDIATE SOURCE:  
 (A) LIBRARY: lambda zapII

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

Cys Asp Asn Gln Lys Ser Cys Met Ser Asn Cys Ser Ile Thr Ser Ile  
 1 5 10 15  
 Cys Glu Lys Pro Gln Glu Val Cys Val Ala Val Trp Arg Lys Asn Asp  
 20 25 30  
 Glu Asn Ile Thr Leu Glu Thr Val Cys His Asp  
 35 40

(2) INFORMATION FOR SEQ ID NO:4:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 44 amino acids  
 (B) TYPE: amino acid  
 (D) TOPOLOGY: unknown

(ii) MOLECULE TYPE: peptide

(vi) ORIGINAL SOURCE:  
 (A) ORGANISM: Homo sapiens

(vii) IMMEDIATE SOURCE:  
 (A) LIBRARY: lambda zapII

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

Cys Ser Ala Asp Tyr Ser Gly Leu Leu Leu Ala Phe Gln Val Phe Leu  
 1 5 10 15  
 Leu Asp Glu Leu Thr Ala Arg Gly Phe Cys Gln Ile Gln Val Lys Thr  
 20 25 30  
 Ala Gly Thr Pro Val Ser Ile Pro Val Cys Asp Asp  
 35 40

(2) INFORMATION FOR SEQ ID NO:5:

(i) SEQUENCE CHARACTERISTICS:  
 (A) LENGTH: 20 amino acids  
 (B) TYPE: amino acid  
 (D) TOPOLOGY: unknown

(ii) MOLECULE TYPE: peptide

(vi) ORIGINAL SOURCE:  
 (A) ORGANISM: Homo sapiens

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## (vii) IMMEDIATE SOURCE:

(A) LIBRARY: Lambda zapII

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:5:

Cys Asp Ile His Val Leu Lys Gln Asp Gly Gln Phe Ser Val Leu Phe  
1                      5                      10                      15

Thr Lys Cys Asp  
20

## (2) INFORMATION FOR SEQ ID NO:6:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 20 amino acids  
(B) TYPE: amino acid  
(D) TOPOLOGY: unknown

## (ii) MOLECULE TYPE: peptide

## (vi) ORIGINAL SOURCE:

(A) ORGANISM: Homo sapiens

## (vii) IMMEDIATE SOURCE:

(A) LIBRARY: Lambda zapII

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

Cys Val Ala Val Trp Arg Lys Asn Asp Glu Asn Ile Thr Leu Glu Thr  
1                      5                      10                      15

Val Cys His Asp  
20

## (2) INFORMATION FOR SEQ ID NO:7:

## (i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 19 amino acids  
(B) TYPE: amino acid  
(D) TOPOLOGY: unknown

## (ii) MOLECULE TYPE: peptide

## (vi) ORIGINAL SOURCE:

(A) ORGANISM: Homo sapiens

## (vii) IMMEDIATE SOURCE:

(A) LIBRARY: Lambda zapII

## (xi) SEQUENCE DESCRIPTION: SEQ ID NO:7:

Cys Gln Ile Gln Val Lys Thr Ala Gly Thr Pro Val Ser Ile Pro Val  
1                      5                      10                      15

Cys Asp Asp

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WE CLAIM:

1. A method for assaying for the presence of a substance that modulates a cytokine of the TGF- $\beta$  superfamily which comprises (a) reacting a substance which  
5 is suspected of modulating a cytokine of the TGF- $\beta$  superfamily with a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain, or a portion or a mimetic thereof, and a cytokine of the TGF- $\beta$  superfamily under conditions where the TGF- $\beta$  binding  
10 compound, and the cytokine are capable of forming a complex, the TGF- $\beta$  binding compound and/or the cytokine being present in a known concentration; (b) assaying for complexes, free TGF- $\beta$  binding compound, and/or cytokine; and, (c) comparing with a control.
- 15 2. A method as claimed in claim 1 wherein the TGF- $\beta$  binding protein contains the TRH1 domain of fetuin as shown in the Sequence Listing as SEQ. ID. NO. 2 and in Figure 8, the TRH1 domain from the TGF- $\beta$  type II receptor as shown in the Sequence Listing as SEQ. ID. NO. 3 and in Figure 8, or  
20 the TRH1 domain from thyroglobulin as shown in the Sequence Listing as SEQ. ID. NO. 4 and in Figure 8.
3. The method as claimed in claim 1 wherein the TGF- $\beta$  binding compound contains the TRH1b subdomain from fetuin, the TGF- $\beta$  type II receptor, or thyroglobulin as  
25 shown in the Sequence Listing as SEQ. ID. NOS. 5, 6, and 7, respectively.
4. The method as claimed in claim 3 wherein the TGF- $\beta$  binding compound contains a sequence which has at least 70% identity with the sequence of the TRH1b subdomain from  
30 fetuin, the TGF- $\beta$  type II receptor, or thyroglobulin as shown in the Sequence Listing as SEQ. ID. NOS. 5, 6, and 7, respectively.



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5. The method as claimed in claim 1 wherein the TGF- $\beta$  binding compound contains a mimetic of the TRH1 domain or TRH1b subdomain.
6. The method as claimed in claim 1 wherein the  
5 cytokine is a member of the TGF- $\beta$  family or DPP/VG1 family.
7. The method as claimed in claim 1 wherein the cytokine is TGF- $\beta$ 1, TGF- $\beta$ 2, BMP-2, BMP-4 or BMP-6.
8. A pharmaceutical composition comprising at least one TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor  
10 and which contains a TRH1 domain or a portion, or mimetic thereof, and a pharmaceutically acceptable carrier, auxiliary or excipient.
9. A pharmaceutical composition as claimed in claim 8 wherein the TGF- $\beta$  binding compound contains the TRH1  
15 domain of fetuin as shown in the Sequence Listing as SEQ. ID. NO. 2 and in Figure 8, the TRH1 domain from the TGF- $\beta$  type II receptor as shown in the Sequence Listing as SEQ. ID. NO. 3 and in Figure 8, or the TRH1 domain from thyroglobulin as shown in the Sequence Listing as SEQ. ID.  
20 NO. 4 and in Figure 8.
10. A pharmaceutical composition as claimed in claim 8 wherein the TGF- $\beta$  binding compound contains the TRH1b subdomain from fetuin, the TGF- $\beta$  type II receptor, or thyroglobulin as shown in the Sequence Listing as SEQ. ID.  
25 NOS. 5, 6, and 7, respectively.
11. A method of treating an individual suffering from a condition requiring modulation of cytokines of the TGF- $\beta$  superfamily comprising administering an effective amount of a composition as claimed in claim 8, or a substance  
30 identified in accordance with the method of claim 1.

- 55 -

12. A method of enhancing in an individual the activity of a growth factor whose effects are overridden by a cytokine of the TGF- $\beta$  superfamily comprising administering to the individual a composition as claimed in claim 8, or a substance which is an antagonist of cytokines of the TGF- $\beta$  superfamily identified in accordance with the method of claim 1.

13. A method for assaying for a cytokine of the TGF- $\beta$  superfamily in a sample comprising (a) reacting a sample suspected of containing the cytokine with a definite quantity of a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain or a portion, or a mimetic thereof, and a definite quantity of the cytokine, under conditions where the compound and the cytokine are capable of forming a complex, the compound and/or the cytokine being present in a known concentration, (b) assaying for complexes, free compound and/or cytokine, and (c) comparing with a control.

14. A method of modulating bone formation in an individual comprising administering an effective amount of a composition as claimed in claim 8 or a substance identified in accordance with the method of claim 1.

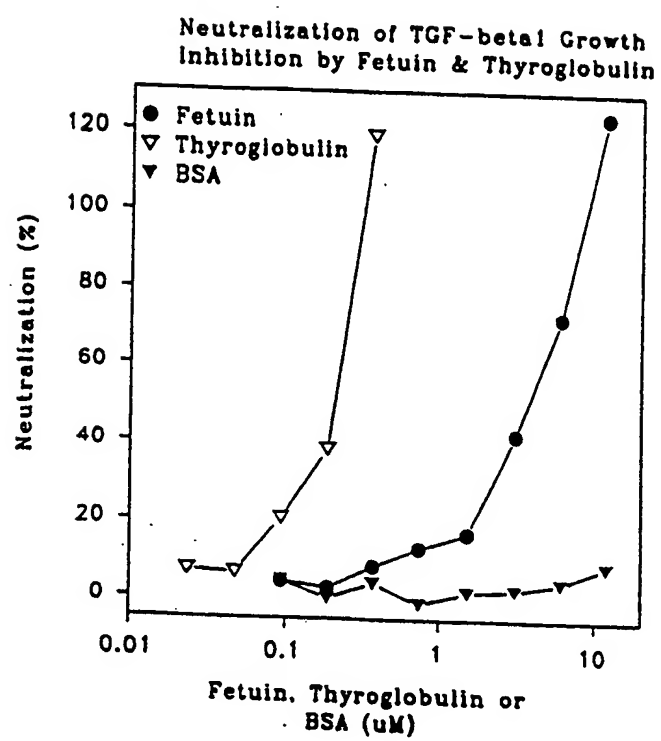
15. Use of an effective amount of a composition as claimed in claim 8, or a substance identified in accordance with the method of claim 1 for treating an individual suffering from a condition requiring modulation of cytokines of the TGF- $\beta$  superfamily.

16. Use of a composition as claimed in claim 8, or a substance which is an antagonist of cytokines of the TGF- $\beta$  superfamily identified in accordance with the method of claim 1, to enhance the activity of a growth factor whose effects are overridden by a cytokine of the TGF- $\beta$  superfamily.

- 56 -

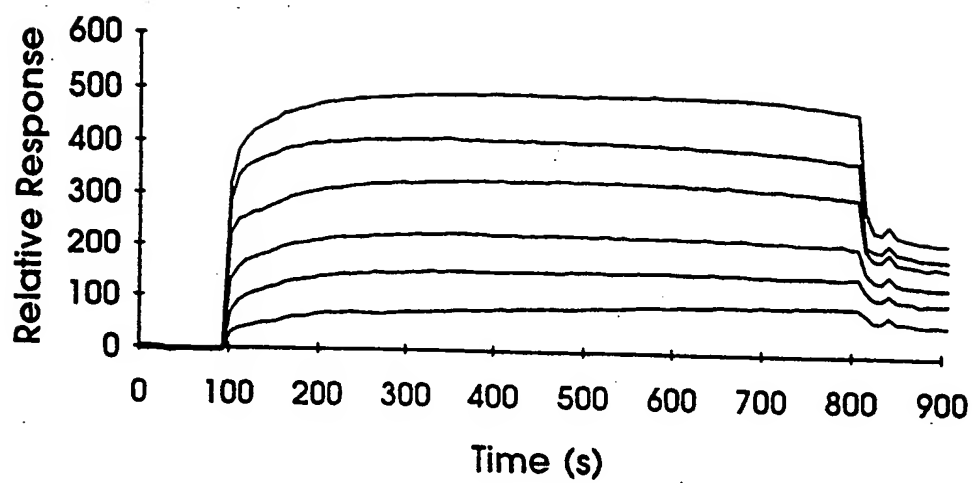
17. Use of a TGF- $\beta$  binding compound which is not a TGF- $\beta$  receptor and which contains a TRH1 domain or a portion, or mimetic thereof, in the preparation of a medicament for treating an individual suffering from a condition requiring modulation of cytokines of the TGF- $\beta$  superfamily.

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FIGURE 1



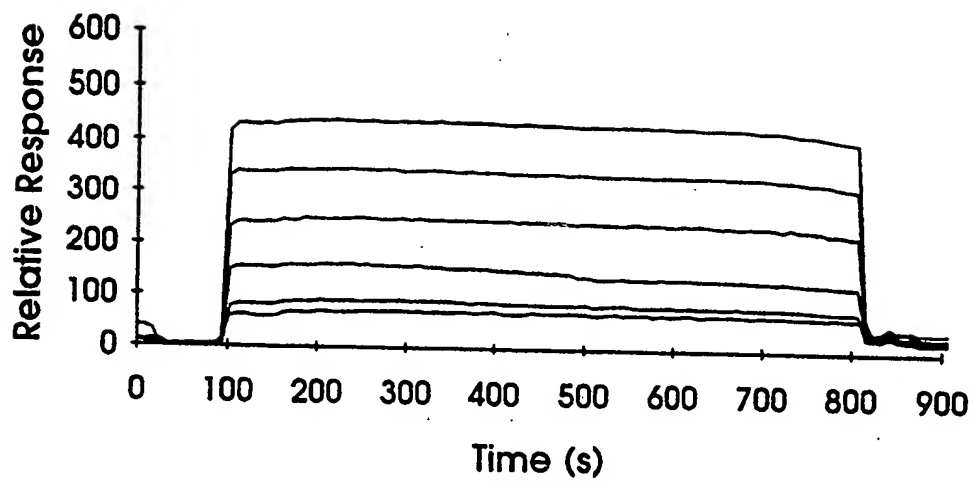
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FIGURE 2



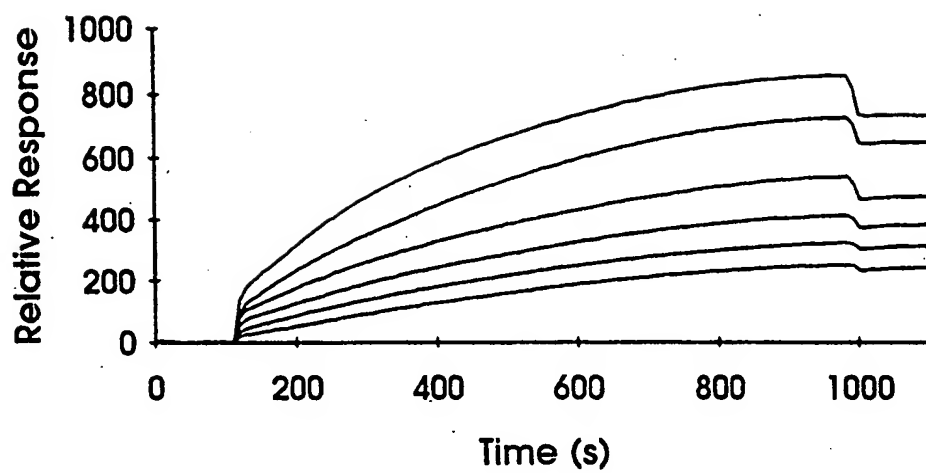
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FIGURE 3



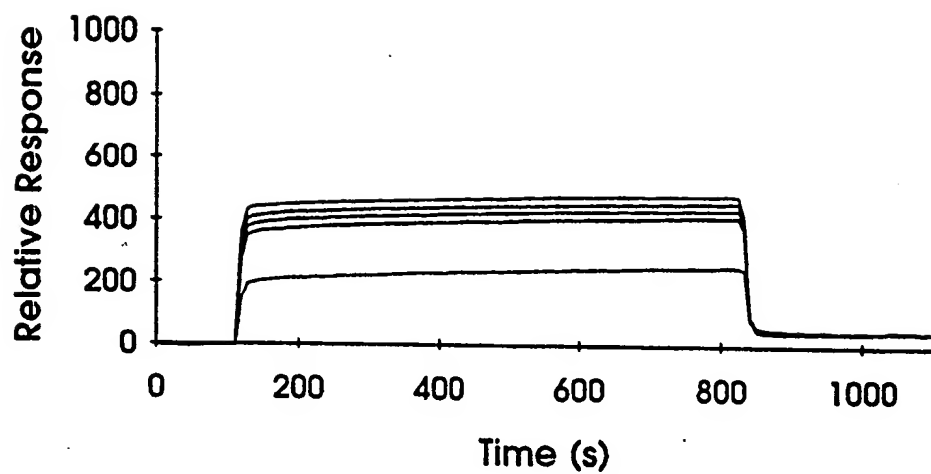
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FIGURE 4



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FIGURE 5



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## FIGURE 6

Multiple alignment project: FETUIN 17-NOV-93 09:31:39

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      TRH1a      TRH1b
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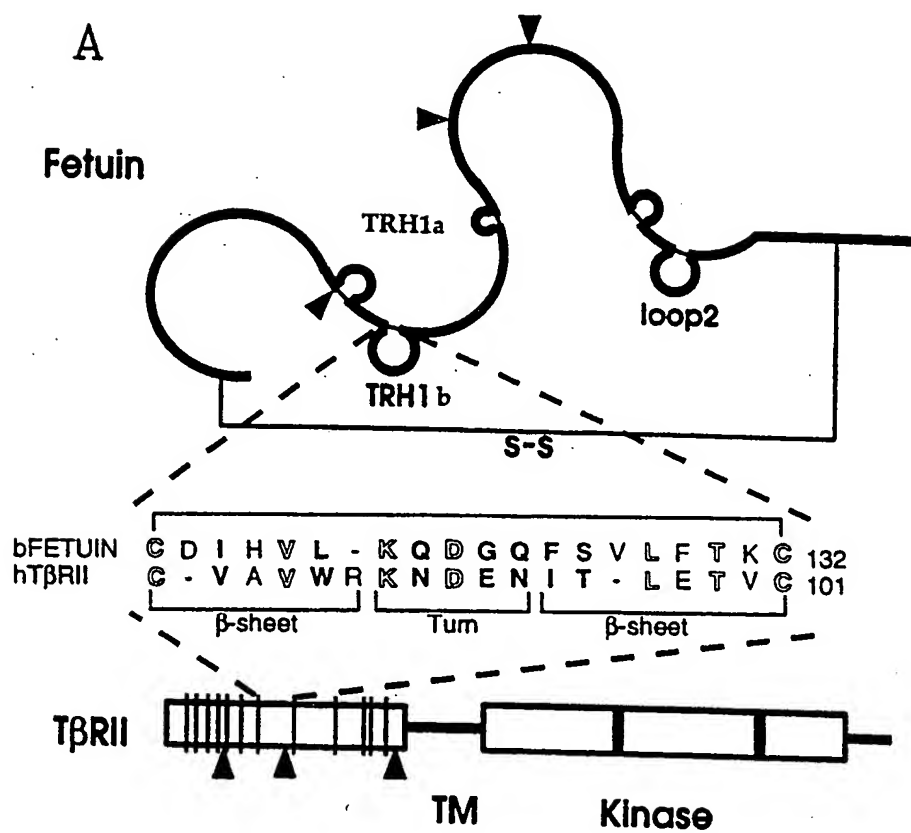
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FIGURE 7

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FIGURE 8

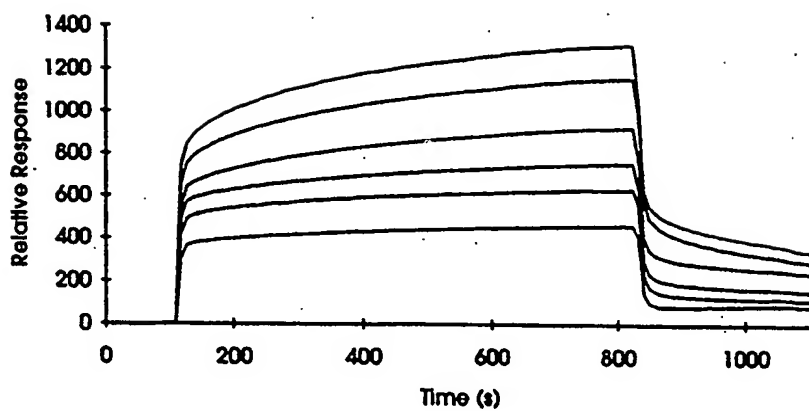
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mTGF-betaRI	GQNED--HC <del>EQG</del> GCSSLSIYDG <del>FHVYK</del> -----GCFQ	72
hTGF-betaRII	CQNOK--SCMS-NC-SITSICEKPQEVC-VAVWRKNQEN-IT-L <del>EIVC</del> D	103
bTHYROGLOBULIN	CSADYSGLLLAFTV <del>LLEDEL</del> -A-RGFCQTQV---KTAGTPVS-I-PVCD	1349
bFETUIN	GHVLDPPTP-LA-NCSVRQQTOHAVEGD <del>CDL</del> V-L-KDDGQ-FSVLFLKC-D	133

**a**   **b**

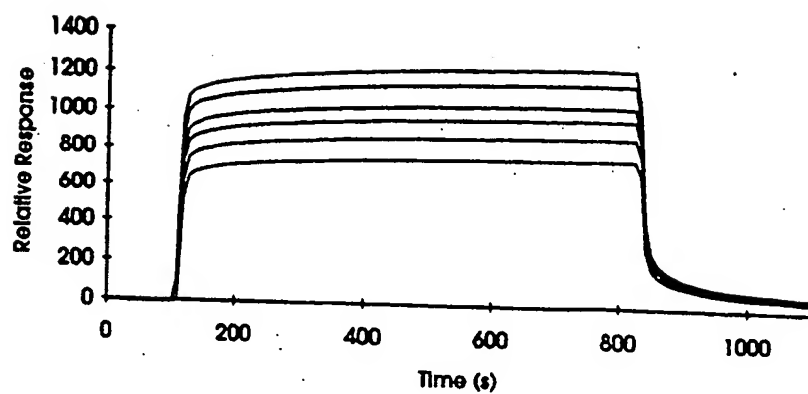
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FIGURE 9



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FIGURE 10



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FIGURE 11

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generated symbols 1 to: 567.

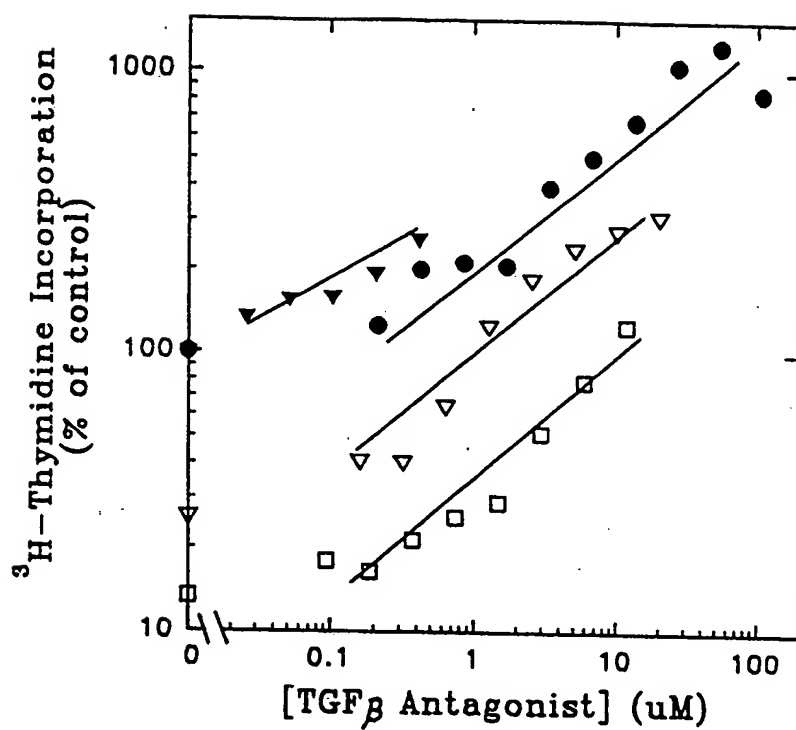
LOCUS HUMTGFBIIIR 2090 bp mRNA PRI 14-JAN-1995  
DEFINITION Human TGF-beta type II receptor mRNA, complete cds.  
ACCESSION M85079  
KEYWORDS transforming growth factor-beta type II receptor.  
SOURCE Homo sapiens (tissue library: lambda zapII) cDNA to mRNA.  
ORGANISM Homo sapiens . . .

M85079.pep Length: 567 June 22, 1995 14:50 Type: P Check: 5743 ..

1 MGRGLLRGLW PLHIVLWTRI ASTIPPHVQK SVNNDMIVTD NNGAVKFPQL  
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101 CHDPKLPYHD FILEDAASPK CIMKEKKKPG ETFFMCSCSS DECNDNIIPS  
151 EYNTSNPDL LLVIFQVTGI SLLPPLGVAI SVIIIFYCYR VNRQKLSST  
201 WETGKTRKLM EFSEHCAIIL EDDRSDISST CANNINHNTL LPIELDTLV  
251 GKGRFAEVYK AKLKQNTSEQ FETVAVKIFP YEEYASWKTE KDIFSDINLK  
301 HENILQPLTA EERKTELKQ YWLITAFHAK GNLQEYLTRH VISWEDLRKL  
351 GSSLARGIAH LHSDHTPCGR PKMPIVHRDL KSSNILVKND LTCCLCDFGL  
401 SLRLDPTLSV DDLANSQVQG TARYMAPEVL ESRMNLNAE SFKQTDVYSM  
451 ALVLWEMTSR CNAVGEVKDY EPPFGSKVRE HPCVESMKDN VLRDRGRPEI  
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551 SCSEKIPED GSLNTTK

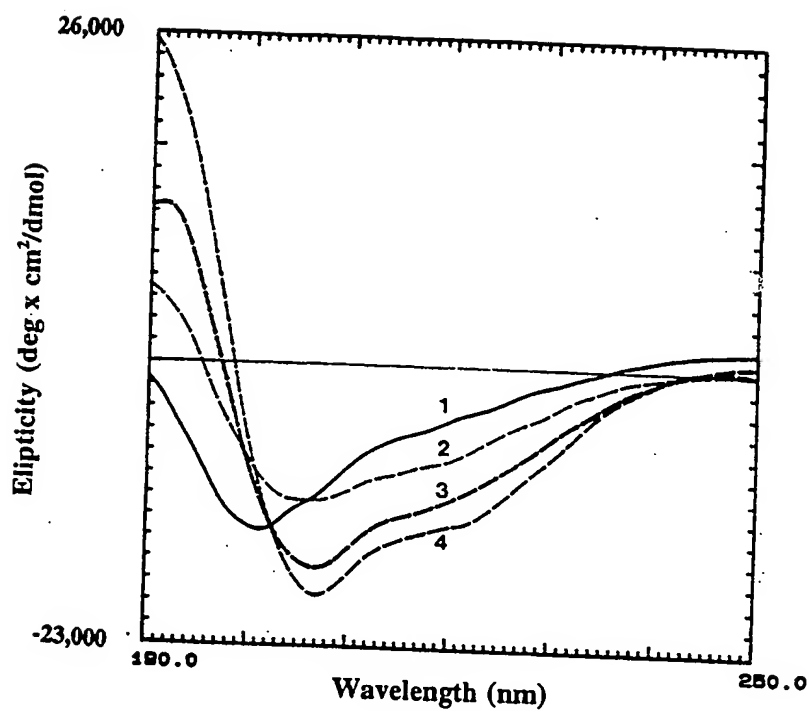
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FIGURE 12



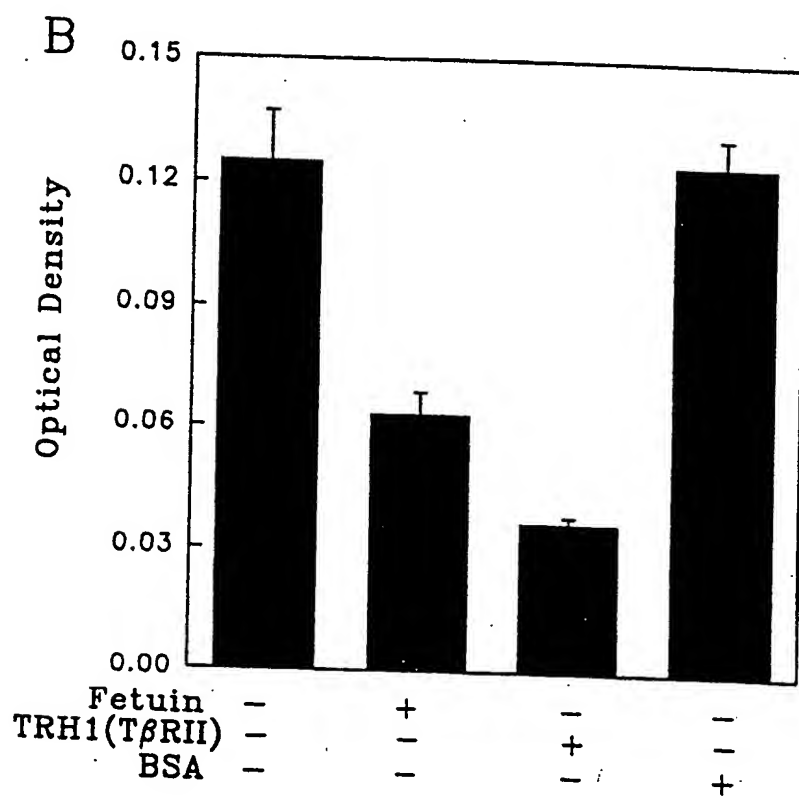
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FIGURE 13



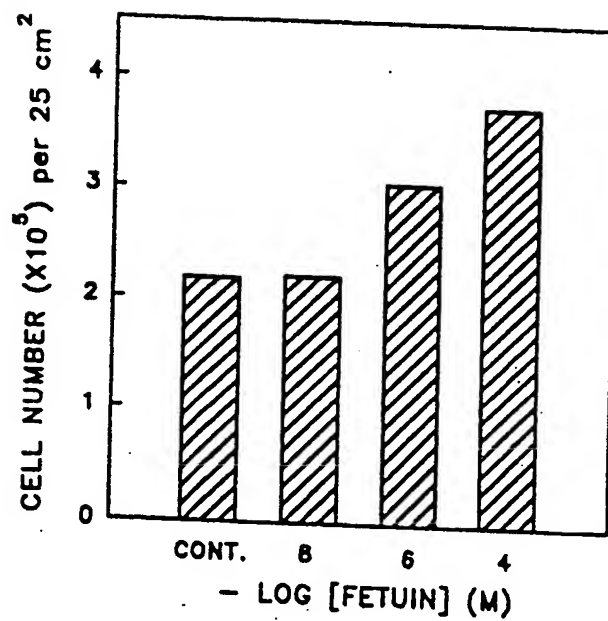
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FIGURE 14

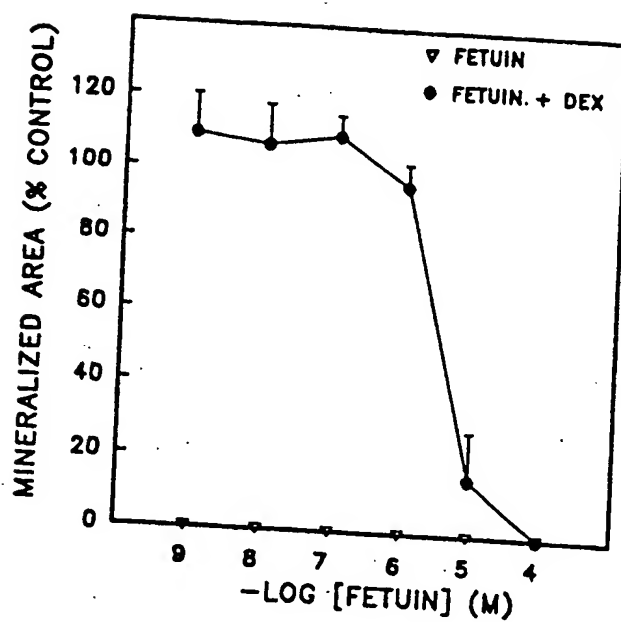
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FIGURE 15



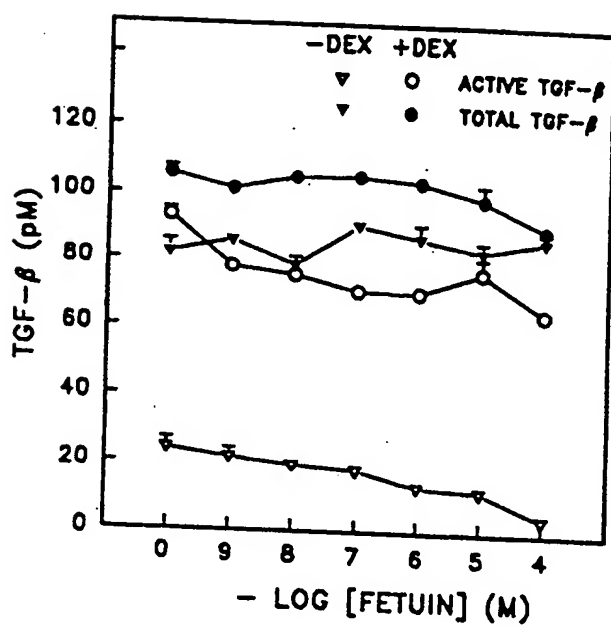
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FIGURE 16



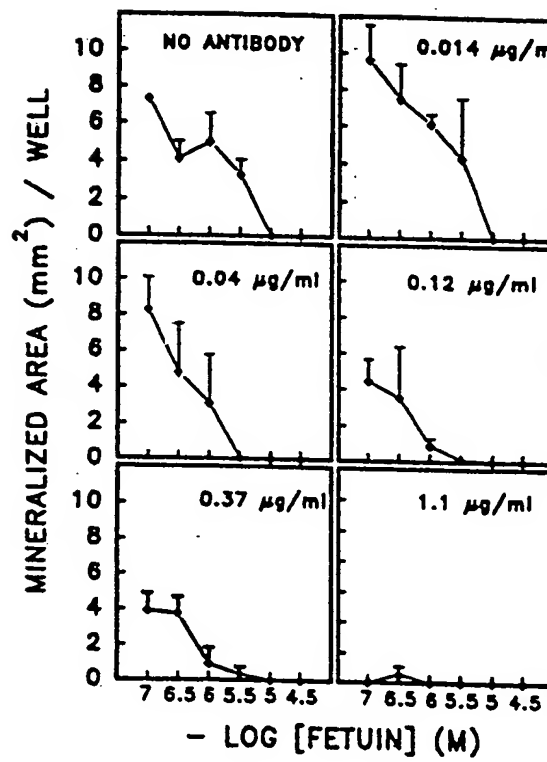
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FIGURE 17



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FIGURE 18



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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/CA 95/00290

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 6 G01N33/50 G01N33/68 A61K38/17

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 6 G01N C07K A61K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	THE JOURNAL OF BIOLOGICAL CHEMISTRY, vol. 265, no. 8, 15 March 1990 pages 4354-4357, K. M. DZIEGIELEWSKA ET AL. 'The complete cDNA and amino acid sequence of bovine Fetuin' ---	
A	CELL, vol. 69, 26 June 1992 pages 1067-1070, J. MASSAGUÉ 'Receptors for the TGF-B family' cited in the application --- -/--	

☒ Further documents are listed in the continuation of box C.

☐ Patent family members are listed in annex.

### \* Special categories of cited documents :

- \*A\* document defining the general state of the art which is not considered to be of particular relevance
- \*E\* earlier document but published on or after the international filing date
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- \*O\* document referring to an oral disclosure, use, exhibition or other means
- \*P\* document published prior to the international filing date but later than the priority date claimed

- \*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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- \*Y\* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
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Date of the actual completion of the international search

30 August 1995

Date of mailing of the international search report

07. 09. 95

Name and mailing address of the ISA

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NL - 2280 HV Rijswijk  
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Fax (+31-70) 340-3016

Authorized officer

Cartagena y Abella, P

# INTERNATIONAL SEARCH REPORT

Inter. Application No  
PCT/CA 95/00290

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>CELL, vol. 68, 21 February 1992 pages 775-785, H. Y. LIN ET AL. 'Expression cloning of the TGF-B type II receptor, a functional transmembrane Serine/Threonine kinase.' cited in the application ---</p>	
A	<p>NATURE, vol. 360, 26 November 1992 pages 361-364, W. A. BORDER ET AL. 'Natural inhibitor of transforming growth factor-B protects against sacrring in experimental kidney disease.' cited in the application ---</p>	
A	<p>NATURE, vol. 346, 19 July 1990 pages 281-284, Y. YAMAGUCHI ET AL. 'Negative regulation of transforming growth factor-B by the proteoglycan decorin.' cited in the application -----</p>	

# INTERNATIONAL SEARCH REPORT

national application No.

PCT/CA95/00290

## Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 11,12,14-16  
because they relate to subject matter not required to be searched by this Authority, namely:  
Remark: Although claims 11,12,14-16 are directed to a method of treatment of the human/animal body, the search has been carried out and based on the alleged effects of the composition.
2. ☐ Claims Nos.:  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.



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